IMPACT OF POSITIONING TECHNOLOGY ON HUMAN NAVIGATION

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By

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ABSTRACT

In navigation from one place to another, spatial knowledge helps us establish a destination and route while travelling. Therefore, sufficient spatial knowledge is a vital element in successful navigation. To build adequate spatial knowledge, various forms of spatial tools have been introduced to deliver spatial information without direct experience (maps, descriptions, pictures, etc.). An innovation developed in the 1970s and available on many handheld platforms from the early 2000s is the Global Position System (GPS) and related map and text-based navigation support systems.

Contemporary technical achievements, such as GPS, have made navigation more effective, efficient, and comfortable in most outdoor environments. Because GPS delivers such accurate information, human navigation can be supported without specific spatial knowledge. Unfortunately, there is no universal and accurate navigation system for indoor environments. Since smartphones have become increasingly popular, we can more frequently and easily access various positioning services that appear to work both indoors and outdoors. The expansion of positioning services and related navigation technology have changed the nature of navigation. For example, routes to destination are progressively determined by a “system,” not the individual. Unfortunately we only have a partial and nascent notion of how such an intervention affects spatial behaviour. The practical purpose of this research is to develop a trustworthy positioning system that functions in indoor environments and identify those aspects those should be considered before deploying Indoor Positioning System (IPS), all towards the goal of maintaining affordable positioning accuracy, quality, and consistency. In the same way that GPS provides worry free directions and navigation support, an IPS would extend such opportunities to many of our built environments. Unfortunately, just as we know little about how GPS, or any real time navigation system, affects

human navigation, there is little evidence suggesting how such a system (indoors or outdoors) changes how we find our way. For this reason, in addition to specifying an indoor position system, this research examines the difference in human's spatial behaviour based on the availability of a navigation system and evaluates the impact of varying the levels of availability of such tools (not available, partially available, or full availability). This research relies on outdoor GPS, but when such systems are available indoors and meet the accuracy and reliability or GPS, the results will be generalizable to such situations.

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Wook Rak Jung

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LIST OF ABBREVIATIONS AND CONCEPTS

AP	Access Point
A-A	Active to Active (No GPS support for the entire route)
A-P	Active to Passive (1^{st} Path: no GPS and 2^{nd} Path: GPS)
ECO	Efficiency, Convenience, and Opportunity
GPS	Global Positioning System
ICT	Information and Communications Technology
IPS	Indoor Positioning System
LBS	Location Based Service
MAC	Media Access Control
P-A	Passive to Active (1^{st} Path: GPS and 2^{nd} Path: no GPS)
P-P	Passive to Passive (GPS support for the entire route)
PDOP	Positional Dilution of Precision
RSS	Received Signal Strength
RSSI	Received Signal Strength Indication
SaskEPS	Saskatchewan Enhanced Positioning System
SMS	Stay on the Meaningful Segment
UofS	University of Saskatchewan
UPS	Ubiquitous Positioning System
WCN	Walkable CentreLINE Network
WiFi	Wireless Fidelity
WPS	WiFi-based Positioning System
GPS-like	Refers to generally accepted accuracy threshold of GPS and used an positioning accuracy of 10 m as GPS-like accuracy

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Human navigation is an essential activity in our day-to-day existence. This is due in large part to its fundamental role in accessing resources (Hund & Nazarczuk, 2009). Successful navigation provides benefits to the individual; unsuccessful navigation can result in being lost or failing to reach a desired destination. When an individual does not have an appropriate level of spatial knowledge to reach a destination, the best-case scenario is a delay in arrival, or the cost of traveling under higher levels of anxiety; in the worst-case scenario, an individual does not reach their desired destination at all. For this reason, humans have developed strategies and techniques to reduce inefficiency and to prevent unsuccessful navigation.

Traditionally, maps and verbal communication have been the most widely used methods for conveying geographic and spatial knowledge (Golledge, 2002; Ishikawa, Fujiwara, Imai, & Okabe, 2008; Montello, 2005). A key problem in verbal or written communication is that most geographic knowledge is highly subjective, based on an individual's memory in both understanding and experiencing the environment in which navigation is to occur (Cornell, Sorenson, & Mio, 2003). As a result, there exists the risk of miscommunication when sharing geographic knowledge or spatial descriptions. In contrast, a map represents spatial information with pre-assigned and generalized symbols (Goodchild, 2007; Goodchild, Fu, & Rich, 2007;

MacEachren, 2004). Because of this decreased subjectivity (not having to interpret the meaning of another person's words), a map is an effective and secure method for sharing geographic knowledge.

While a single map cannot contain all spatial observations necessary for navigation and interpretation, even in the range of intra-urban walking distance, a series of maps could present cumulative change in an environment (Jung, 2009). One important concern for mapping is the age of the information (how current it is). The generalization principle in cartography ensures that not ALL information is portrayed, but for the information that is included, a map is likely to contain invalid geographic information (past information: on the map but not currently present in the environment) as well as valid geographic information (current information). In recent years, our urban environments have expanded in both horizontal and vertical dimensions; this urban expansion presents greater challenges to our navigational abilities, even with existing spatial tools.

The growth of Information Technology (IT) has reduced spatiotemporal limitations in both information-gathering and delivery of up-to-date information. In most developed countries, we now access and obtain geographic information easily and travel further distances to a greater number of destinations than ever before; in effect, our travel opportunities have increased enormously. Consequently, we must acquire more geographic knowledge for efficient and effective navigation in a greater number of new environments (Bell & Saucier, 2004; Golledge, Dougherty, & Bell, 1995). Faster and more secure ways of delivering accurate geographic knowledge are therefore required to support successful navigation (Ishikawa, Murasawab, & Okabeb, 2009).

As a result of our continued pursuit of improving human navigation efficiency and effectiveness, many innovative and ubiquitous navigation tools have been introduced. In particular, Global Positioning Systems (GPS), mobile computing, and ubiquitous sensor systems are noteworthy. Consequently, handheld mobile devices include GPS, which provides ubiquitous outdoor positioning information, and several additional sensors (Bluetooth, WiFi, accelerometers, gyroscopes, cameras, etc.) that can support a variety of specific and general applications (Steiniger, Neun, Edwardes, & Lenz, 2008). Such devices (smart phones, specifically) meaningfully reduce the effort needed to acquire the necessary spatial knowledge for navigation (Takemiya & Ishikawa, 2013). These services can also deliver tailored geographic information including current location and suggested routes based on time and distance, anytime and anywhere (Hirtle & Raubal, 2013).

Current ubiquitous navigation technologies allow us to move through novel spaces more conveniently with less preparation than when learning occurs prior to experiencing and environment for the first time or when learning happens without support (incrementally). As smartphones become increasingly popular, demand for seamless positioning and navigation support has increased. Despite this, current technology is limited to providing accurate location outdoors. Many commercially developed IPSs are orders of magnitude less accurate than GPS, which is not available indoors (Jung & Bell, 2013; Jung, Bell, Petrenko, & Sizo, 2012).

At present, most individual’s routine and sometimes vital activities take place indoors; furthermore we are spending increasing amounts of time in indoor spaces (Klepeis et al., 2001). Indoor spaces differ from outdoor space in many ways; for instance, when pointing to unseen objects we point more accurately to indoor targets than to outdoor (Berry & Bell, 2014; Li, 2008); today’s indoor spaces are also quite different from indoor spaces of the past (current spaces are expansive, multi-story, and complicated). An inherent characteristic of indoor space when compared with outdoor space is that indoor spaces are dis(inter)connected by various architectural features (Beaumont, Gray, Moore, & Robinson, 1984; Montello & Pick, 1993) and indoor spaces have more standardized / identical spatial configurations which can confuse our ability to differentiate one locale from another (Montello & Sas, 2006). In other words, outdoor spaces have more memorable characteristics that intuitively support navigation (Holscher, 2012; Lawton 1996; Montello, 2004). Lastly, daily indoor navigation is associated with both horizontal and more dramatic vertical movement (i.e. stairs or elevators) which is a substantial departure from our historic outdoor navigation (Hölscher, Brösamle, & Vrachliotis, 2012; Montello & Pick, 1993). These spatial characteristics of indoor environments present navigational challenges. Fortunately, GPS successfully supports human navigation in real-time and outdoor situations, but cannot provide the same experience indoors. Many Indoor Positioning Systems (IPS) have been developed as a complementary positioning tool for indoor environments, but none achieve GPS accuracy or are commercially available (Bell, Jung, & Krishnakumar, 2010; Li, Salter, Dempster, & Rizos, 2006); while this presents an excellent opportunity, there are many limitations for expanding IPS technologies, such as signal blockage in indoor environments or the high cost of deploying the positioning services (Jung & Bell, 2013).

1.1.1 Fundamental Requirement for GPS-like Indoor Positioning Service

Human navigation performance can vary based on individual levels of knowledge about space, as gathered through experience and learning (Kalff & Strube, 2009), but also based on differences among environments. Because of this, it may be necessary to have a variety of spatial awareness strategies associated with different levels of knowledge and for different environments. For example, in an urban environment when an individual is new to a city, familiarization with local configurations and physical patterns is necessary. In contrast, if an individual has lived in the same city for a prolonged period of time, predicting the configuration and composition of that urban environment is easier (Gärling, Book, & Lindberg, 1984; Lawton, 1996). Additionally, the efficiency of spatial learning is dependent on spatial uniqueness. Generally, individuals experience more difficulty creating spatial knowledge in environments with fewer spatial features (Kaplan, 1976). For this reason, individuals may have more difficulty becoming familiar with indoor environments vs. outdoor environments. Disorientation problems are more common indoors due to fewer distinguishable features (Weisman, 1981) and increased complexity (Li, 2008).

Indoor spaces have a relatively cellular form and multiple cells are either connected or disconnected through a range of architectural components such as doors, floors, walls, corridors, and stairs. Such components might provide the features necessary to support navigation, but they also might cause confusion if the sub-structures are similar (Beaumont et al., 1984; Carlson, Hölscher, Shipley, & Dalton, 2010). Furthermore, indoor spaces offer limited sightlines caused by architectural constraints and repeated cellular and structural patterns. Due to these indoor characteristics, we typically experience difficulties in describing indoor environments to others (Weisman, 1981).

Indoor navigation can be supported by IPS with detailed graphical or verbal descriptions (Pradhan, Ergen, & Akinci, 2009), however such systems are not universally available at GPS resolution (Giudice, Walton, & Worboys, 2010; Jung et al., 2012). Many commercial IPS do exist, nevertheless these tend to be either location specific systems (only working in certain locations) or sensor specific systems (inconsistent positioning accuracy due to unreliable and incomplete senor information) (Bell et al., 2010; Rao & Fu, 2013; Tippenhauer, Rasmussen, Popper, & Capkun, 2009). If an IPS were to be universally available with consistent accuracy, it would have the potential to be a complementary indoor positioning service. Many indoor fixed radio signals, including WiFi, have recently shown promise in reducing indoor navigation limitations. These radio signals can be used for positioning without employing new infrastructure (LaMarca, Hightower, Smith, & Consolvo, 2005). Wireless Internet services are available in many indoor spaces; therefore, existing WiFi services which use WiFi-routers can be used to develop IPSs as an alternative, or supplement, to GPS. WiFi can be an efficient and cost-effective foundation for indoor navigation systems due to its provision of dense wireless coverage in different types of indoor spaces including universities, airports, and shopping centers. Following the development of a proper positioning algorithm, WiFi-based IPS can be easily established, providing an indoor positioning solution without the necessity of constructing additional infrastructure.

1.1.2 Questions Regarding Ubiquitous Navigation Technology Uses

Navigation systems allow humans to navigate more effectively and efficiently in a variety of environments (Allen, 1999). A navigation system is a system that supports route planning or provides route information and navigation status based on location information derived from a positioning system (Farrell & Barth, 1999). Necessary positioning information (absolute location) is provided by a positioning system that determines accurate positioning information based on a specific senor network using a surveying and positioning technique/algorithm. For instance, GPS normally deliver accurate location information to the individual user without associated spatial and environmental information; however, once GPS's location information is connected with the visible extent of the surrounding environment and route information, a GPS-based navigation system support a user's turn-by-turn navigation in real time manner.

Both the expansion of use and development of other technology-oriented navigation tools has affected the nature of human navigation (Ishikawa, Fujiwara, Imai, & Okabe, 2008). A navigation system enables travel without prior knowledge or experience of a space; as a result, we lose navigational autonomy whereby destinations and travel routes are increasingly selected by the navigation system rather than the individual. This changes our navigation mode from active to passive. With passive navigation, individuals are given navigational information from a navigation system (or are lead by someone else) without prior spatial or route awareness and no longer make active decisions concerning their navigation, but will rather passively follow the guidance of the system. The quality of the acquired spatial knowledge differs between active and passive attention in a new environment (Conniff, Craig, Galan-Diaz, & Laing, 2010). During active navigation, an individual must pay attention to the environment and rely on their own knowledge to determine their current location, while a passive traveler can accurately determine their current location from a GPS. We do not currently know enough about how navigational tools impact human navigation and spatial knowledge acquisition. At the same time, there are demands for more efficient and seamless navigation tools as the use of location-aware mobile devices is growing for both outdoor and indoor environments (i.e. cellphones, smartphones, laptops, and other mobile devices). The question remains as to whether or not we truly need navigation tools beyond maps and verbal communication. If innovative navigation tools can help to find a destination efficiently with reduced disorientation, what information needs to be communicated to humans before and after use? And what are the implications of using a form of assistance that might not be reliable?

1.2 RESEARCH OBJECTIVES AND DESIGN

Most ubiquitous positioning systems are not truly ubiquitous, *"existing or being everywhere at the same time."* Many current positioning systems fail to maintain adequate positioning accuracy in indoor environments. Furthermore, even if a ubiquitous positioning system is available everywhere, we do not know how our behaviour is modified and how can we use those systems constructively and confidently.

The purpose of this research is twofold: 1. to increase the completeness and usability of a ubiquitous positioning system based on improving both technical and cognitive aspects of the system, and 2. to examine the situations under which navigation systems might compromise the navigation process. From a technical standpoint, this research is focused on finding cost-effective and innovative approaches to establish that a WiFi-based positioning system can deliver GPS-like positioning information. The technical requirements of the system itself and accessible infrastructure were identified that allowed us the capacity to measure potential positioning quality and challenges before deploying a WiFi-based IPS. This step would also identify where WiFi-based IPSs offer good accuracy (and consequently where they are less accurate). For the cognitive component, this research concerns how GPS affects human navigation and wayfinding behaviour. Furthermore, I examine how human navigation behaviour changes based on different conditions during continuous navigation.

1. Define the technical requirements and challenges for successfully extending positioning systems from outdoor to indoor environments cost-effectively
    - Evaluate the most important considerations for building the database of WiFi-based navigation systems
    - Identify the relationship between number of WiFi-routers and positioning quality, including positioning error and positioning consistency
    - Classify the benefits of a well-designed and data-rich database for an indoor positioning system
    - Rank the most influential problem for maintaining acceptable positioning services indoors
    - Clarify the impact of individual problems on the positioning quality

- Identify stable solutions based on both technical and practical assessment

2. Examine the human spatial behavioural impact of a forced transition from *active* (that which is done without supporting system; the individual is responsible for maintaining and updating orientation) to *passive* navigation (that which is done without sufficient critical reasoning and in the presence of a navigation support system)

    - Measure the difference in human spatial behaviour based on availability of real-time navigation assistance
    - Identifying the impact of navigation either with or without real-time navigation assistance, as well as the impact of varying levels of availability of such tools (not available, partially available in either indoors or outdoors, full availability)
    - Clarify the benefits of using a ubiquitous positioning system and what factors should be cautiously concerned for minimizing negative impact from using a ubiquitous positioning system

1.3 THESIS STRUCTURE

A conceptual representation of the research procedure consists of four steps: first, the SaskEPS is introduced for extending reliable positioning to indoor spaces. Second, the limitations of current IPSs and the distinctiveness of SaskEPS are reviewed. Third, the strengths and benefits of using the SaskEPS are presented. Fourth, the potential problems for expanding SaskEPS and other IPSs is reviewed and optimal solutions and improvements stated. Finally, the impact of ubiquitous navigation technology on human navigation is examined.

Chapter 1 provides research background and motivations, research objectives, and a brief summary of each thesis chapter.

Chapter 2 clarifies the limitation of current Indoor Positioning Systems (IPS) and reviews the currently used technologies and techniques for IPS. Most importantly, Saskatchewan Enhanced Positioning System (SaskEPS) is introduced with innovative approaches to increase accessibility and usability of the system.

Chapter 3 addresses the usability and efficiency of SaskEPS. The strength of SaskEPS stems from its database. This research is focused on the fact that many existing IPS problems can be attributed to a poorly designed database; therefore, this study aims to describe how to build secure and reliable databases for other IPSs. In addition, this study examines the role of WiFi density (number of available WiFi routers) to ensure GPS-like positioning quality for indoor spaces. SaskEPS and many IPSs still require improvements in positioning quality; however in general, IPSs can potentially expand location trustworthy of the ubiquitous positioning system and turn-by-turn navigation indoors.

Chapter 4 evaluates the potential obstacles to extend a ubiquitous positioning system to indoor spaces from a geographers' point of view. Previous studies examine potential problems with indoor navigation using a "top-down" approach beginning with a theoretical review and addressing potential problems; in contrast, this study utilizes a "bottom-up" approach beginning with an assessment of the actual physical space to be studied, followed by the measurement of the severity of potential positioning errors during practical use of IPSs. The severity of potential errors is addressed with potential solutions.

Chapter 5 addresses the differences in human spatial behaviour based on the variable availability of a navigation system during wayfinding. This study examines human navigation as dependent on the either the presence or absence of a navigation system, as well as the impact of varying the levels of availability of such tools. Individuals can accomplish successful and efficient navigation without GPS, however if participants make any mistakes during navigation, the cost tends to be high. On the other hand, while GPS assistance may help individuals save time, reduce disorientation, and prevent unnecessary travel during wayfinding, it may not ensure complete knowledge development for later navigation performance. This research will shed light on the benefits of ubiquitous positioning system in addition to the concerns we must keep in mind when using such technologies.

Chapter 6 summarizes experimental findings and presents a discussion of the conclusions reached during this research. In addition, certain limitations and future directions are highlighted.

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CHAPTER 2

INTRODUCING A REAL TRUSTWORTHY INDOOR POSITIONING SYSTEM: THE SASKATCHEWAN ENHANCED POSITONING SYSTEM

2.1 INTRODUCTION

Over 1 billion worldwide consumers actively use a smartphone (Gallagher, Patel, Hageman, Llanos, & Partisano, 2014). Location-aware service applications that allow a user to identify relative spatial information and to detect accurate geographic position have emerged as a value-added component of Global Positioning System (GPS) (Junglas & Watson, 2008; Steiniger, Neun, & Edwardes, 2006). A location-aware service can be served with a software-based application that is capable of delivering accurate geographic information based on integration with functionality of a mobile device; currently location-aware service applications are highly dependent on GPS for geographic information (Bell, Jung, & Krishnakumar, 2010).

While various mobile devices, especially smartphones, are increasingly popular, GPS have been widely accepted as the primary positioning application for mobile devices (Bell et al., 2010; Steiniger et al., 2006). GPS is capable of producing reliable and accurate location services in most outdoor environments, but GPS is often limited in indoor environments due to signal attenuation (Borriello, Chalmers, LaMarca, & Nixon, 2005). For this reason, indoor location-aware services need an alternative positioning source to support seamless location-aware services. The benefits of using location-aware services that are based on a software-based application are that even if specific functionality is inaccessible, it is able to engage with novel functionality based on overriding an unconventional value on alternative sensors in mobile devices. As a result, many Indoor Positioning Systems (IPS) have been established to deliver equivalent positioning experience in both outdoor to indoor environments.

GPS was originally developed for military use; however, it is also available for civilian use. Civilian use of GPS has increased since 1996, when public positioning error was reduced after the removal of selective availability (Clinton, 2000). Selective availability is selective availability of the accurate GPS signals that only available for military use of GPS, so civilian use of GPS was relatively inaccurate while selective availability was “turned on” (over 20 meters of positioning error). A minimum of 24 GPS-satellites in a medium earth orbit produce accurate and reliable positioning with sub-10 meters of error in most outdoor environments (El-Rabbany, 2002). Nevertheless, the GPS signal is relatively weak, so its positioning service is limited in indoor environments where GPS signals cannot penetrate. The outdoor environment is mostly open and continuous, so accurate positioning service can be produced with a 24 satellite array. For indoor environments, individual buildings are often isolated from each other, so an independent positioning source for each structure is required; however, this requires much effort and cost to offer a fully operational indoor positioning service. Fortunately, wireless fidelity Internet (the WiFi-network) is commonly available in many indoor environments (Gallagher, Li, Kealy, & Dempster, 2009; Torrens, 2008). If this WiFi-network can be used for indoor positioning then a seamless positioning service would be accessible for both indoor and outdoor environments.

2.2 STRENGTH OF WIFI SENSOR AS SUPPORTING INDOOR POSITIONING SERVICES

Various sensors have been tested for indoor positioning, but there are challenges faced by each sensor's distinctive characteristics. The types of sensors that have been utilized for an IPS can be categorized into two broad sets: hardware-oriented sensors and software-oriented sensors (Table 2.1).

Table 2.1 Comparison of Hardware-oriented and Software-oriented sensors

Sensor Type	Technology	Uses	Advantages
Hardware-oriented	Require specific hardware or infrastructure for the positioning service	Produce location-specific positioning systems with optimal hardware for the target environment	High positioning accuracy
Software-oriented	Use commonly available hardware on top of the present infrastructure	Add new values on the available hardware with a software-based application	Easy accessibility

First, hardware-oriented sensors are focused on delivering reliable indoor positioning services with specialized sensors such as Ultra Sound, Ultra-wide Band (UWB), Radio-Frequency Identification (RFID), Ultra High Frequency (UHF), and Infrared (IR) (Gu, Lo, & Niemegeers, 2009; Liu, Darabi, Banerjee, & Jing, 2007). These sensors require purpose-built hardware, infrastructure, or both, but these sensors have the advantage of being built for indoor positioning. Due to high infrastructure cost, hardware-oriented sensors might be useful for individual buildings or smaller spaces that require accurate indoor positioning services, but might not be feasible for extensive deployment and will cause difficulty in system-to-system integration. (Table 2.2).

Table 2.2 Comparison of Positioning Accuracy based on Sensors (Liu, et al., 2007)

Accuracy	Sensor Type	Positioning Algorithm Advantages
Less than 1 meter	UWB, Microwave	Angle of Arrival Time Difference of Arrival
About 1 meter	RFID, Ultrasonic	Fingerprinting
1 – 10 meters	WLAN, Bluetooth, A-GPS	Fingerprinting Trilateration
Over 10 meters	Mobile Cellular Signal	Fingerprinting Trilateration

Even though individual sensors and algorithms have advantages and disadvantages, when a proper combination of a sensor and an algorithm reliable positioning service in GPS-free environments with low-cost can be deployed (Liu, et al., 2007); however environmental and technological noise needs to be managed, this can be done with an adequate positioning algorithm or specific sensors which include significantly less noise in the selected environment, but it may result in a higher cost system (Brooks, Makarenko, Kaupp, Williams, & Durrant-Whyte, 2006). But hardware-oriented systems also have a noticeable advantage; once the specific sensor set is installed, an indoor positioning system could be deployed in the environment where such sensor networks are available (Yick, Mukherjee, & Ghosal, 2008).

Second, software-oriented sensors establish an IPS based on existing infrastructure by adding new functionality in addition to the intended functions. WiFi, A-GPS, Cellular, and Bluetooth are broadly adopted as software-oriented IPSs (Bell et al., 2010; Kodippili & Dias, 2010). These software-oriented sensors are generally deployed for tasks other than positioning (information transfer, device connection, etc.); therefore, these types of systems generally require an additional adjustment to use as an IPS (Table 2.3). Their primary advantage is that no additional infrastructure or hardware is required. Without concerted effort software-oriented sensors may present relatively low positioning accuracy; however, an important attractive feature is their ubiquitous availability indoors and they are generally common across different spaces/implementations.

Table 2.3 Commonly available sensors in most mobile devices

Sensor	Original Purpose	Limitation in Indoors
A-GPS	Mostly outdoor positioning	Signal Interfering
Cellular Network	Voice / Data communication	Poor positioning accuracy
Bluetooth	Short range data transfer	device required/short signal penetration
WiFi	Wireless Internet connection	Signal confusion and multipath

Fortunately, WiFi is an attractive sensor that can be used for several alternative purposes without additional hardware modification or compromising their intended use (Gallagher et al., 2009). For this reason, WiFi has been used as the cornerstone for complementary IPSs. Furthermore, WiFi is easily accessible in indoor environments (WiFi-router) with mobile devices (WiFi-modem) (Bell et al., 2010). Many commercial WiFi-based Positioning Systems (WPS) have been introduced but such systems have difficulty achieving adequate accuracy because of unanticipated interference from architectural features (Feng, Au, Valaee, & Tan, 2010). In addition, as with all sensors deployed with software-based systems, WiFi was not originally developed to support positioning, so there are unforeseen challenges to achieving this value-added aspect of WiFi functionality; therefore, many existing commercial and non-commercial WPSs exist but are not yet compatible with GPS-based positioning systems in terms of accuracy and availability (Bell et al., 2010; Gallagher et al., 2009; Tippenhauer, Rasmussen, Popper, & Capkun, 2009). Consequently, there is still a gap in positioning service efficiency between outdoor and indoor environments due to the lack of reliable indoor positioning.

In an attempt to produce a WIFI-based positioning system, the Saskatchewan Enhanced Positioning System (SaskEPS) was developed in 2010 (Bell & Jung, 2010). Initially, SaskEPS was designed to produce GPS-like positioning in indoor environments that was accessible and expandable; therefore currently available WPSs were reviewed to identify limitations that may negatively impact positioning accuracy or implementation cost.

2.3 DATA REQUIREMENT FOR A WIFI-BASED POSITIONING SYSTEM

Data quality and assurance of the WPS database is a core factor in producing indoor positioning with acceptable positioning accuracy (Bell & Jung, 2010; Tippenhauer et al., 2009). The WPS database contains detailed information about individual WiFi-routers (unique identifier, location, signal proliferation pattern and a WiFi signal heat map) and provides essential data for location determination (Jones, Liu, & Alizadeh-Shabdiz, 2007). Unfortunately, many well-known WPSs, such as iOS and Android, utilize unreliable databases; data in these databases were collected inaccurately or there was no clear data quality standard or quality control process for data (Bell et al., 2010; Tippenhauer et al., 2009). To avoid data quality issues, SaskEPS's database was developed and populated with accuracy, completeness, and trustworthiness in mind (Figure 2.1).

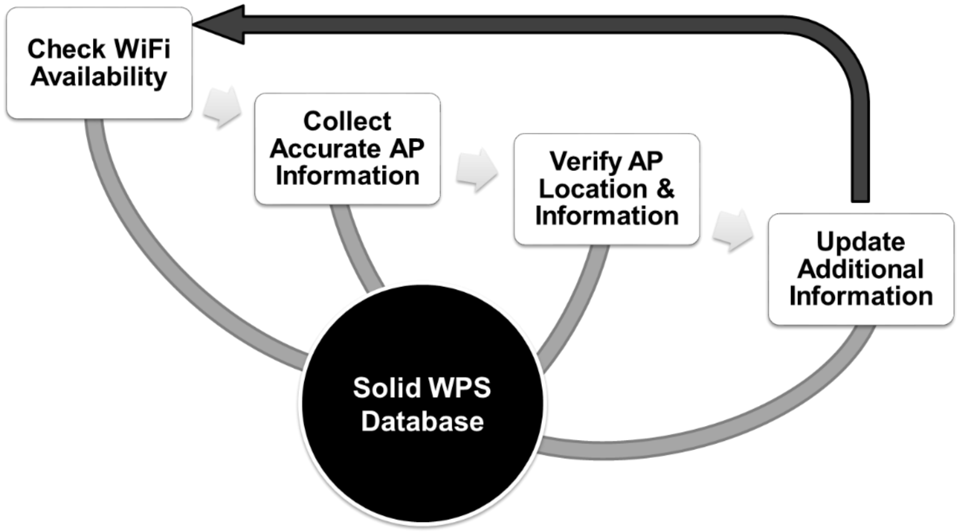

Figure 2.1 Fundamentals of data collection

The SaskEPS database creation process was divided into four steps. First, WiFi- signal coverage was reviewed for campus buildings at the University of Saskatchewan. During this process, available Access Points (APs) were mapped and estimated WiFi-signal coverage was produced based on spatial interpolation (Figure 2.2). WiFi-connectivity across campus was then evaluated. Second, a GIS-based database was created using validated AP information. All AP locations were mapped based on CAD-drawn blueprints cross-referenced with a campus map in ArcGIS and detailed AP information was also recorded (this included Media Access Control (MAC) address, verbal location description, building name, and floor information). Third, the database was verified by visiting and visually verifying individual APs. Accurate AP locations and correct MAC addresses were updated in this process. Fourth, once the GIS-based database was verified, exact X-Y coordinate and additional location classifiers were added. Additional location classifiers referred each AP's relative location (in the corridor, in the room, in the skywalk, and outdoor).

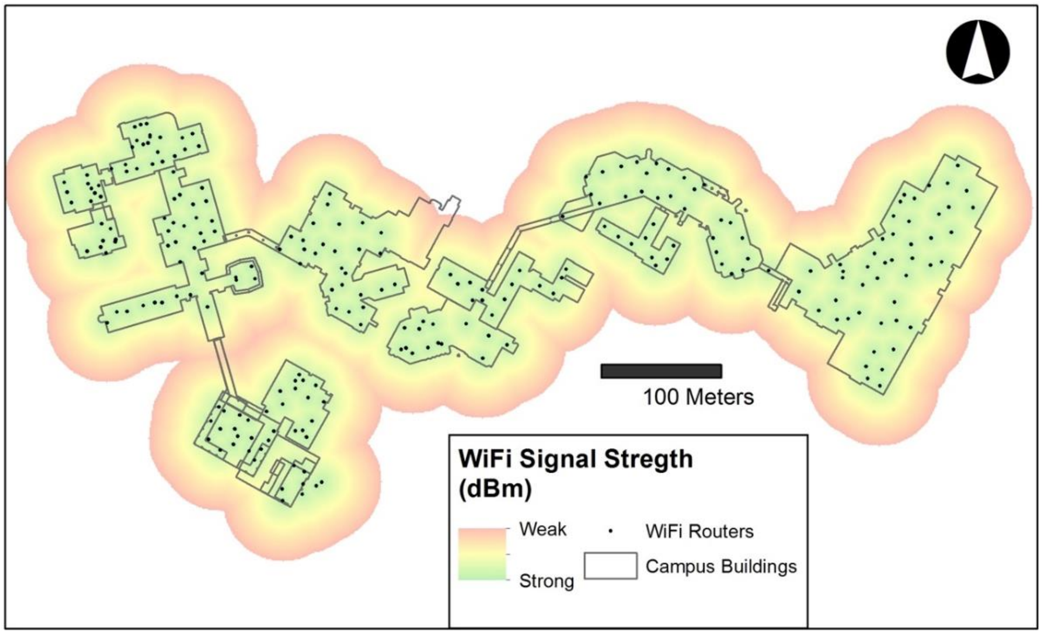

Figure 2.2 Estimated WiFi coverage of core campus buildings at the University of Saskatchewan

2.4 LOCATION DETERMINATION PROCESS

Once the WPS database is successfully established, it provides the necessary information to a positioning algorithm in order to determine a person's (device's) current position. Fingerprinting and trilateration algorithms are widely used for location determination in WiFi-based systems. Fingerprinting determines location based on finding matched Received Signal Strengths (RSS) signatures (fingerprints) between a pre-surveyed radio map and detected WiFi RSSs for a location (Kaemarungsi & Krishnamurthy, 2004; Machaj & Piche, 2011). A comprehensive database of all possible WiFi signatures is required. (Youssef, Agrawala, & Shankar, 2003). From a mapping perspective this is composed of the signal strengths for all routers "visible" from individual points in space. These points are associated with grid cells; grid cell size corresponds to the spatial resolution of the system. Importantly, RSS records cannot normally be directly measured for each grid cell, so sample RSSs are collected from selected locations and non-selected locations' RSSs are estimated based on a mathematical filtering process (Kalman filter or spatial interpolation). The fingerprinting method then compares what is detected by a receiver (smartphone) and compares the signature to the database to determine a user's location (Figure 2.3).

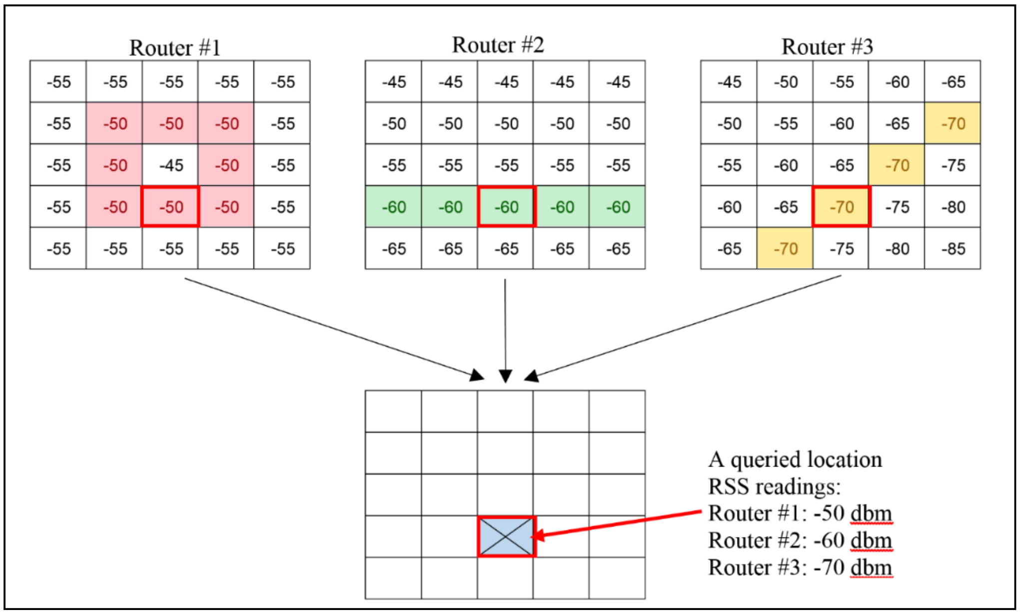

Figure 2.3 An example of the fingerprinting algorithm

The trilateration method is a surveying technique that determines the absolute location of a target feature (unknown location) based on measuring the distance between an unknown location and three known locations (Manolakis, 1996). The trilateration method has been adopted for GPS to generate reliable positioning information in outdoors. However, the trilateration method has been shown to have difficulty generating sub 1 meter positioning accuracy, as has been demonstrated with fingerprinting (Li et al., 2006) but the trilateration algorithm is resilient across various indoor environments and over time (Bell et al., 2010). For example, the fingerprinting method requires a unique WiFi-signal degradation pattern (the radio map) for individual environments. Furthermore, if there are nominal changes in the WiFi-array, such as AP malfunction or AP replacement, new signal patterns have to be mapped. In comparison, the trilateration algorithm can perform even if some APs are not available or new routers are installed but not yet part of the router database (Bell et al., 2010; Jung & Bell, 2013). The trilateration algorithm requires exact WiFi-router location and each router's unique identifier. From this information, and the router's signal, the trilateration algorithm will obtain Euclidian distance information (estimated by RSS) between a queried location and a WiFi-router. For the trilateration algorithm to work, line-of-sight connections between APs and an indoor positioning system receiver is required to obtain accurate distances between a queried location and visible APs in the covered area (Hölzl, Neumeier, & Ostermayer); however three spheres' intersection is usually presented as an overlapping area, not a point, so an additional step is required to determine a centre point of three spheres' overlapping area (Figure 2.4).

Some researchers suggest that a fingerprinting algorithm would assure better positioning accuracy than trilateration algorithm for the WiFi-based IPS (Lemelson, Kopf, King, & Effelsberg, 2009; Li, Salter, Dempster, & Rizos, 2006; Li, Tan, & Dempster, 2010; Mok & Retscher, 2007; Soonjun, Promwong, & Cherntanomwong, 2009), the fingerprinting algorithm is more popularly used for existing WPSs. On the other hand, the fingerprinting algorithm requires mapping the complete signal propagation pattern for an entire area; therefore, plentiful signal reading records and complicated mathematical filters are required to estimate WiFi-signal readings in a corresponding location. For this reason, fingerprinting method is a signal matching technique between multiple signal reading of queried locations and estimated signal propagation patterns of each AP in the area. On the contrary, the trilateration algorithm is capable of delivering GPS-like positioning accuracy and it can be adopted to the WPS with less effort and time than the fingerprinting algorithm as previously explained (Bell et al., 2010).

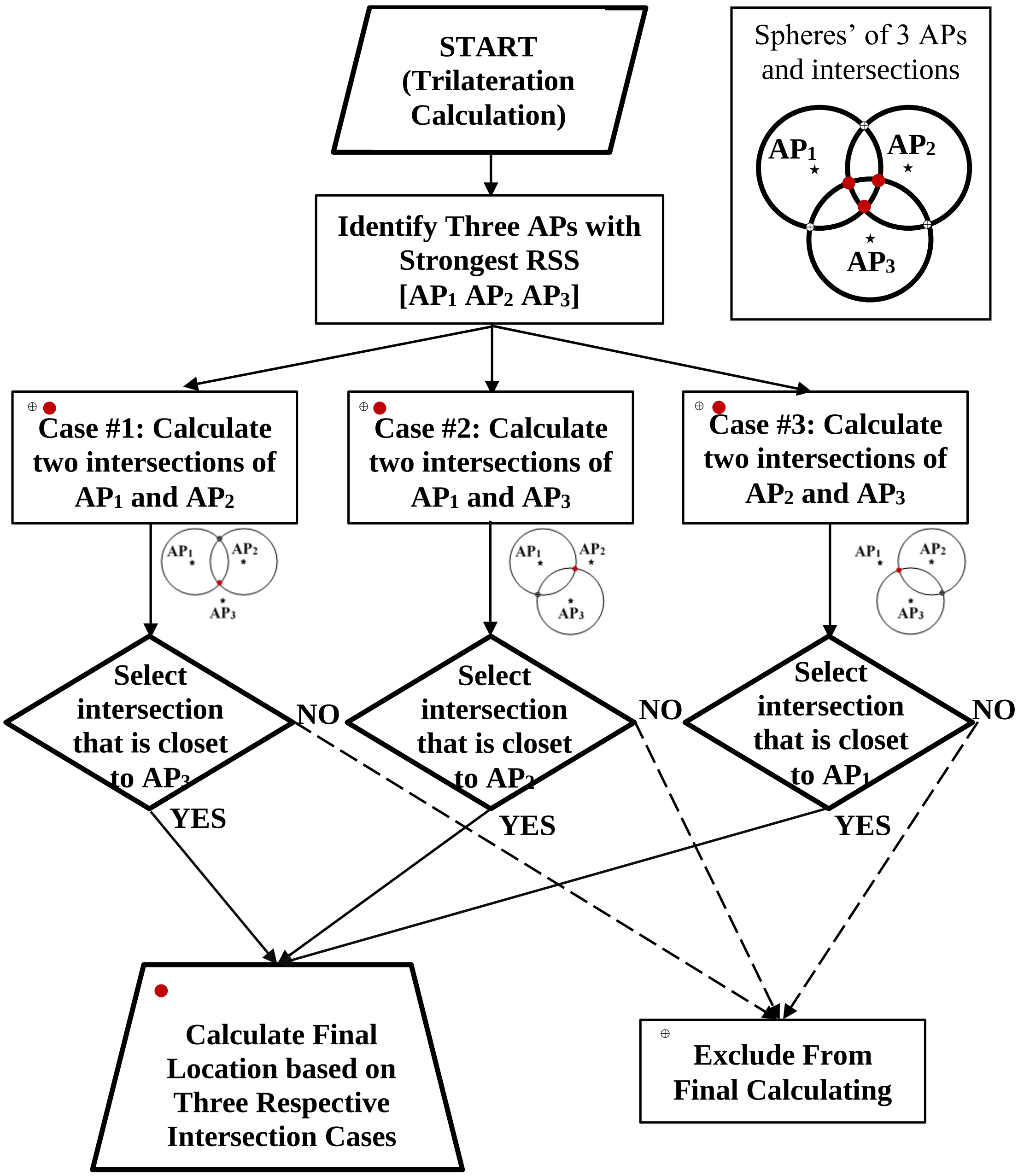

Figure 2.4 An example of the trilateration algorithm calculation procedures

2.5 VITAL CONSIDERATIONS FOR AN INDOOR POSTIONING SYSTEM

Many indoor environments are constructed with multiple floors, so vertical positioning information will be an important issue for users (Table 2.4). In addition, our visible ranges are highly limited indoors, so we often have a hard time identifying current macro-level location information (building names and floor information) (Weisman, 1981).

Table 2.4 Comparison of the essential difference between indoor and outdoor space

Scale	Larger space	Smaller space
Visual Range	Generally wider viewable range	Generally limited viewable range
Visual	Generally more spatial information (landmarks & signs)	Limited applicable and unique spatial information
Vertical	Generally continuous landscape	Many multi-floor settings
Others	Natural and built environments Mostly continuously connected	Additional constraints Mostly disconnected among individual buildings

Unfortunately, most commercial WPSs only provide micro-level positioning information (X-Y coordinate) without macro-level positioning information. Based on this review process, SaskEPS is intended to increase the reliability of the WPS database, the efficiency of positioning determination process, and the legitimacy of indoor positioning. As a result, SaskEPS produces 2.5 dimensional positioning consisting of GPS-like 2D positioning along with nominal floor information and current building name (Bell et al., 2010; Jung & Bell, 2013).

For validating SaskEPS's functionality, SaskEPS and other commercial WPSs were tested in selected buildings of the University of Saskatchewan campus where dense WiFi coverage was available (Table 2.5). SaskEPS's positioning result was much more logical and better quality than other WPSs. For example, SaskEPS positioning error stayed sub-10 meter during the entire experiment (for all random location) but other tested WPSs often showed over 20 meters of positioning error and sometimes exceeded more than several kilometers (Bell et al., 2010).

Table 2.5 Positioning error comparison in test buildings

Building Name	**Errors in Meters**	
	SaskEPS	**iPhone**
Building #1	5.07	26.32
Building #2	6.97	73.77
Building #3	5.23	28.40
Building #4	5.88	38.37

Importantly, SaskEPS's positioning results stayed within each building's footprint. In comparison, other tested WPSs' positioning results (such as iOS) were frequently displayed outside of a building (Figure 2.5). SaskEPS showed promise as a complementary positioning source for indoor environments. On the other hand, more investigation is required to increase SaskEPS usability, see chapters 3 & 4.

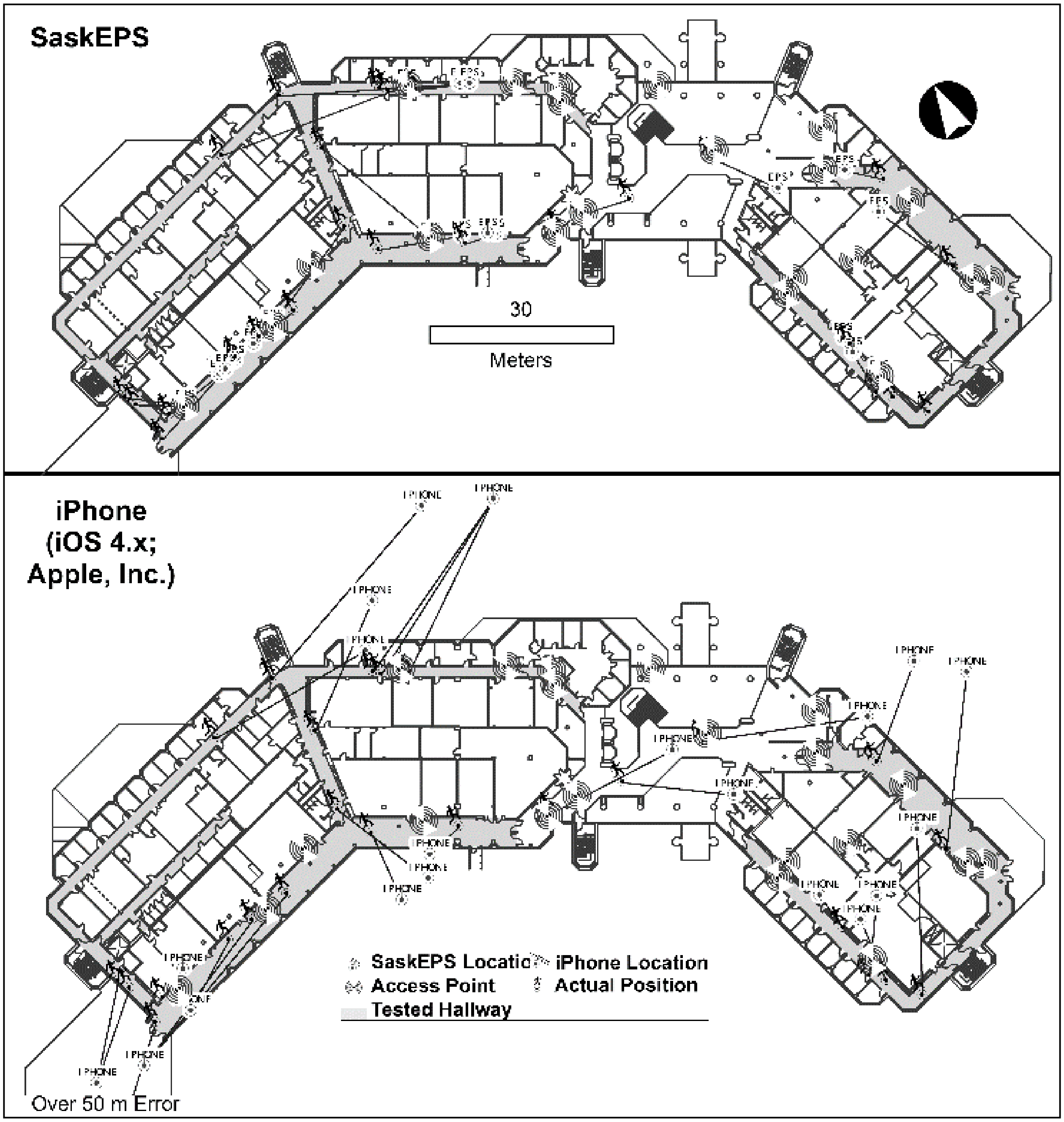

Figure 2.5 Test Result Comparison in building #4: SaskEPS and Commercial WPS (iPhone)

2.6 CONCLUSION

Recent advances in GPS and smartphone technology has made a wealth of location, geographic, and navigation information available for our daily activities. GPS-based navigation systems can assist human navigation in various environments; however indoor environments pose a particular challenge due to the degradation of the GPS-signal as it penetrates walls. Indoor environments are also complicated navigational settings as the visible extent of the surrounding environment is limited. In order to overcome some of the challenges associated with indoor navigation, a WiFi-based indoor positioning system called the Saskatchewan Enhanced Positioning Systems (SaskEPS) has been developed.

The quality of the WPS database is important for positioning accuracy and reliability. Problems such as those presented in this chapter will degrade a user's trust in WPSs. This distrust deters users from considering WPS as an alternative or supplemental positioning service, even where the system functions well. In contrast, SaskEPS is designed to reduce unreliable information in the database for better positioning. SaskEPS's positioning accuracy and consistency are significantly enhanced than other commercial WPSs through the well-designed database. It has been tested in several buildings at the University of Saskatchewan and successfully provided adequate positioning accuracy (sub 10 meter) for locations that were tested. In conclusion, SaskEPS's solid database would be a key element for better indoor positioning and SaskEPS's trilateration would provide a significant advantage to be as a universal IPS.

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CHAPTER 3

QUANTITATIVE COMPARISON OF INDOOR POSITIONING ON DIFFERENT DENSITIES OF WiFi ARRAYS IN A SINGLE ENVIRONMENT[1]

3.1 INTRODUCTION

Now more than ever, humans are being exposed to new technologies and are becoming increasingly intelligent technology users. Many advanced technologies have contributed to making our lives more convenient and efficient while simultaneously making us increasingly technology dependent. Global Positioning Systems (GPS) have become increasingly ubiquitous as we strive for efficient and successful wayfinding (Borriello, Chalmers, LaMarca, & Nixon, 2005). These technologies represent the most recent in a long line of innovations that have altered the navigation and wayfinding process (Bell & Saucier, 2004). Recently, there has been a dramatic increase in the demand for innovative navigation technology due to the emergence and popularity of Location Based Services (LBS) (Raper, Gartner, Karimi, & Rizos, 2007).

LBSs are only serviceable if the device on which they are being delivered can be accurately located; in most cases LBSs use GPS to provide location information with high location certainty in nearly all outdoor environments (little variance in both horizontal and vertical error across different locations) (Bargh & Groote, 2008; Steiniger, Neun, & Edwardes, 2006). Despite success

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in outdoor environments, LBSs are extremely limited in most indoor environments due to ineffective GPS services. GPS is capable of delivering appropriate positioning information for successful outdoor navigation; however, when a user enters an indoor environment, positioning accuracy dramatically decreases (Zandbergen, 2009). To combat this, several alternative or complementary Indoor Positioning Systems (IPS) have been developed (Kolodziej & Hjelm, 2006). Unfortunately, many IPSs have been less impressive than one might expect (Fallah, Apostolopoulos, Bekris, & Folmer, 2013). In order to meet some of the challenges associated with indoor positioning, a WiFi-based positioning system called the Saskatchewan Enhanced Positioning System (SaskEPS) has been developed and tested in multi-building settings on an academic campus.

3.2 ADVANCES IN WiFi-BASED INDOOR POSITIONING

Many WiFi-based Positioning Systems (WPS) have been established to provide trustworthy and complementary indoor positioning services, all with the goal of developing a truly Ubiquitous Positioning System (UPS) (Meng, Dodson, Moore, & Roberts, 2007). Lately, many advanced mobile devices include various sensors that can be employed for tasks beyond their original purpose, these include Assisted-GPS, WiFi, Bluetooth, and accelerometers. This complex functionality allows WPS to provide indoor positioning services with an alternative extension of the WiFi-network (in particular, WiFi positioning accesses the beacon signal that is available without authentication). In addition, most WPSs are software-based systems that can be developed as cross-platform applications. These WPSs can be used to explore aspects of indoor positioning and the extension of such positioning to various value-added applications.

Various WPSs are already available to the public; however, most of these require improvement to attain GPS-like accuracy and ubiquity. Such WPS match WiFi readings at a current location with WiFi information held in a database. The WPS database primarily provides information to the positioning algorithm in order to define a current location; therefore, the WPS algorithm continuously matches what it detects in the environment with information held in a database. Current WPSs, such as those available on iPhone and Android smartphones, usually provide services for wide areas. A principle WPS obstacle is the collection of the necessary information for such a database, which characteristically contains a unique ID known as a Media Access Control (MAC) address for each router-based Access Point (AP), with accurate location or WiFi-fingerprint (WiFi-Radio map) information (Soonjun, Promwong, & Cherntanomwong, 2009; Tippenhauer, Rasmussen, Popper, & Capkun, 2009).

Many WPSs deal with source data that is collected via unreliable, unstable, and unsecure methods. These methods produce data which may be unverifiable due to one or more of the following reasons: user submitted information without any confirmation / validation, wardriving (estimated source information), third party information, or tracking/gathering of users' position including visible AP information. We consider such methods "top-down" as they attempt to build a WPS database with an emphasis on ease and efficiency of data collection (Tippenhauer et al., 2009). Such data is stored in a WPS database without being adequately validated. For example, Skyhook Wireless states that their WPS database is maintained efficiently by a database optimization process (SkyhookWireless, 2010; Zandbergen, 2011) that is not clearly articulated (Klepeis et al., 2001). As well, Apple and Google do not make clear statements regarding their WPS database and accuracy control (Bell & Jung, 2010). The optimization process utilized by Skyhook Wireless sorts valid from invalid AP information in the database (which is not manually or externally validated) based on users' location and visible AP information. This process is susceptible to potential risks, as users may provide incorrect or out-of-date information to commercial WPS vendors (Tippenhauer et al., 2009).

The WPS database is a core component of most WiFi-based positioning services. It should be noted that although these systems use a fingerprinting method, such methods have shown to be highly accurate when deployed systematically. The fingerprinting method is widely used for WPSs. This method records Received Signal Strength Indication (RSSI) at regular locations in the database, then determines a user's location based on finding the pattern of RSSI in the database that matches what is sensed in the environment by a mobile device (Bahl & Padmanabhan, 2000; Shin, Jung, Yoon, & Han, 2011). If the AP database is not kept current, both Type I (false positive) and Type II (false negative) errors are possible. Type I errors occur when the array of signals a mobile device detects matches a database record that corresponds with a location that is not the device's current location. A type II error occurs when the array of signals (and RSSIs) detected by a mobile device does not match any record in the fingerprinting database (Bell & Jung, 2010). For this reason, WPSs often employ individual optimization processes for sorting reliable information in the database; unfortunately, these database optimization processes are rarely clarified (Bell & Jung, 2010; Widyawan, Klepal, & Pesch, 2007).

3.2.1 Saskatchewan Enhanced Positioning System: SaskEPS

Unlike commercial 2-dimensional WPSs, SaskEPS is designed to produce "2.5-dimensional" positioning services. Such positioning results consist of GPS-like 2-dimensional positioning (X, Y coordinates) along with nominal floor information (Table 3.1).

Table 3.1 Comparison table: SaskEPS, and commercial WPS

	SaskEPS	Commercial WPS
Spatial Extent	Indoors	Urban centers and indoors
Technology	WiFi-based	WiFi-based
Devices	Most WiFi-enabled mobile devices	Most WiFi-enabled mobile devices
Algorithm	Trilateration (convert RSS [dBm] to distance)	Commonly, fingerprinting and trilateration
Positioning Quality	2.5 dimensional (X-Y coordinate and floor information)	2 dimensional (X-Y coordinate)
Database	Required	Required
Data Collection	AP information (X-Y location, MAC address)	Signal strengths in specific locations and estimated AP location
Data Control	Surveying for correct AP information	Wardriving, VGI, and user data

SaskEPS is capable of establishing a device's vertical (floor) position by leveraging each AP's floor location. SaskEPS's multi-scheme positioning algorithm allows production of 2.5-dimensional positioning that defines a location profile (building name and floor information) based on fingerprinting methods and exact horizontal location with trilateration methods (Jung, Bell, Petrenko, & Sizo, 2012). For these reasons, SaskEPS's positioning accuracy is more dependent on source data quality than other WPSs (Bell, Jung, & Krishnakumar, 2010).

The SaskEPS database is created and maintained using precisely surveyed AP information. We consider this approach to be "bottom up" as it builds the database with the goal of collecting AP information as accurately and thoroughly as possible. SaskEPS has shown that it can produce more accurate indoor positioning partially due to the availability of a reliable database. SaskEPS results have demonstrated sub-10m average error and high location certainty (low error variance) compared to existing commercial WPSs (Figure 3.1).

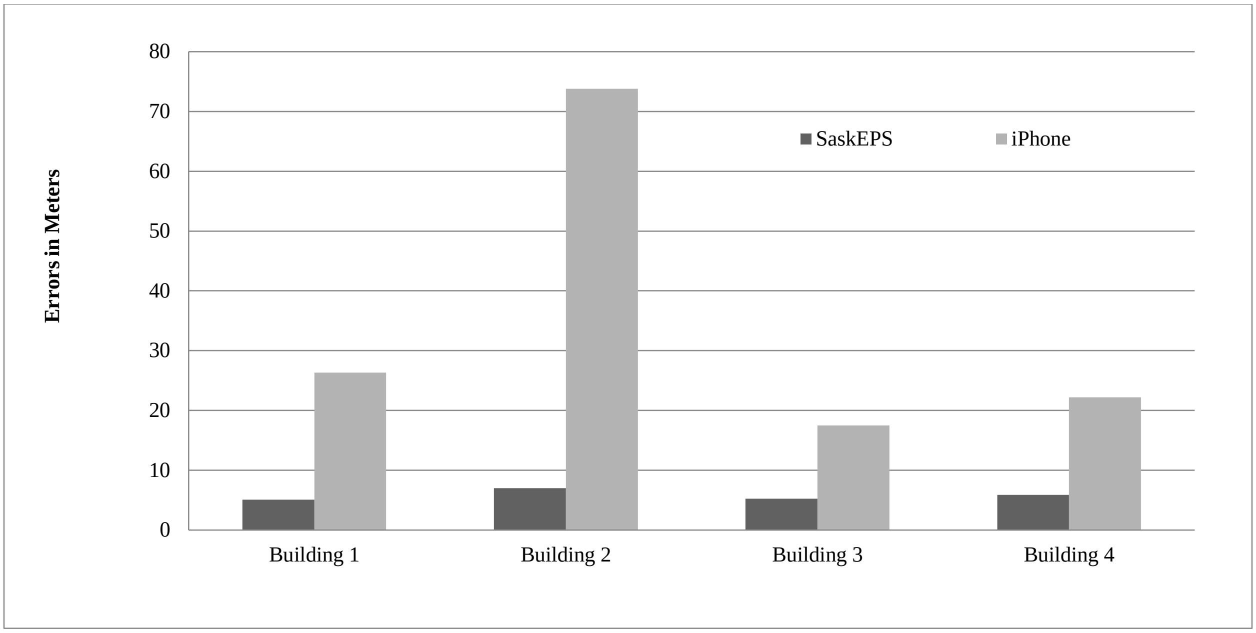

Figure 3.1 Comparison results of average errors in four different campus buildings at the University of Saskatchewan

In addition, SaskEPS is capable of tracking the availability of APs using a real-time comparison of data from the database and recent device activity logs. A secure and verified database not only ensures a reduction in positioning error but also works to maintain an optimally functioning WiFi network. SaskEPS employs a multi-scheme indoor positioning algorithm for location finding (Figure 3.2). A well-developed fingerprinting method alone may produce lower average positioning errors but is more labor intensive (Lim, Jang, Yoon, & Han, 2013; Widyawan et al., 2007) also requires WiFi signal reference points information for developing a radio map (Li, Salter, Dempster, & Rizos, 2006); in contrast, the trilateration method produces GPS-like positioning accuracy with less computational effort (Gallagher, Li, Kealy, & Dempster, 2009).

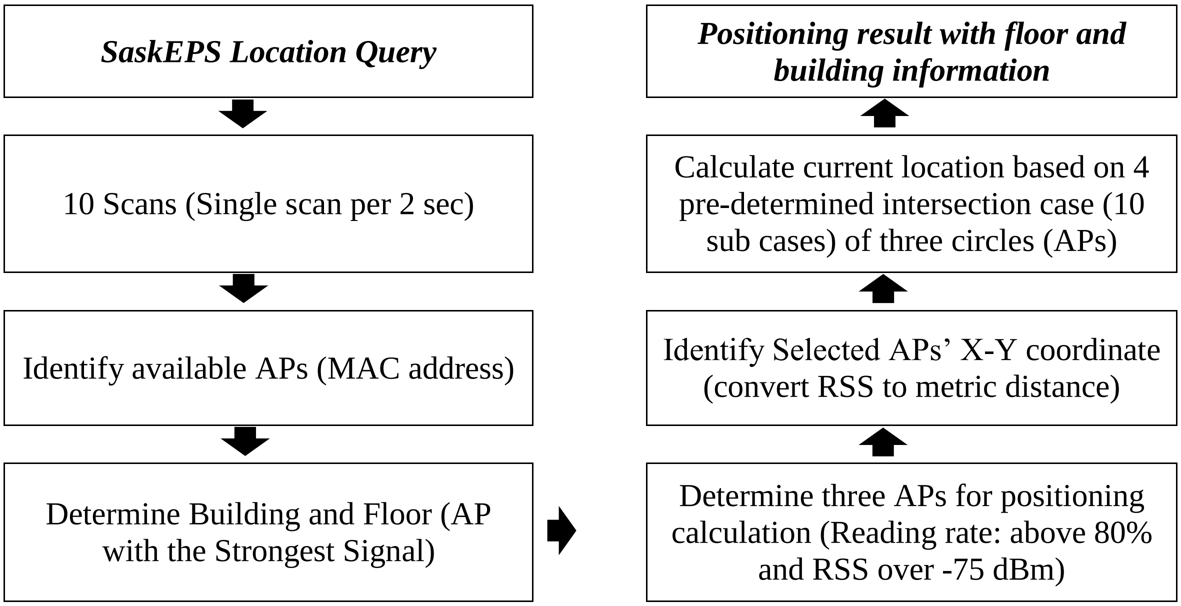

Figure 3.2 SaskEPS algorithm's brief workflow
**Reading rate represents successfully recorded RSS in single duty cycle (10 scans)*

The distinguishing characteristic of the trilateration method is that unlike the fingerprinting method, trilateration is not susceptible to interference by nominal changes to the AP array or database updates (Bell & Jung, 2010). The trilateration method can continuously produce positioning service as long as it can acquire necessary information from three visible APs. The multi-scheme algorithm which employs both fingerprinting and trilateration methods under an accurate and reliable database distinguishes SaskEPS from existing publicly available services. Additionally, the similarity in positioning accuracy (and sub-10 meter positioning error) of SaskEPS and GPS increases the usability and efficiency of LBSs in both outdoor and indoor environments. SaskEPS holds much potential as an indoor positioning system, however key factors which may influence its positioning accuracy and location certainty must be considered.

3.3 EXPERIMENTAL DESIGN

The University of Saskatchewan provides a very dense publicly available WiFi network. The core area of campus is covered by a dense array of APs, with the number of APs having increased every year since 2010. The Facilities Management Division (FMD) and Information and Communications Technology (ICT) groups are engaged in a partnership that installs and maintains the publicly available network. Both units have collaborated on the current research presented in this work. The total number of installed APs increased almost two-fold in the six months between June 2010 and December 2012, from about 700 to over 1800 available APs across campus. WiFi density in many campus buildings increased dramatically over this period, with further plans to increase AP installation (Figure 3.3). In addition, APs installed across the UofS campus are more or less uniform, allowing for little to no signal variation being generated by APs.

Updating the APs (and the resulting change in WiFi density) allows for a comparison of SaskEPS positioning accuracy across different buildings with different AP densities. Similar to previous research (Bell et al., 2010), we will compare SaskEPS accuracy to a commercial system. To test overall positioning accuracy in different indoor environments, SaskEPS was evaluated in four campus buildings, covering 16 different floors.

Twenty-five random points were selected for each floor, totaling 400 different study points. Various mobile devices (one running SaskEPS, and others running competitive WPSs) were tested at each location a minimum of two times to compare results between day (relatively high internet and human traffic) and night (relatively low internet and human traffic). As new APs were added to the network array, we returned to the affected locations for further testing. This allowed us to examine the role that WiFi density plays in positioning accuracy.

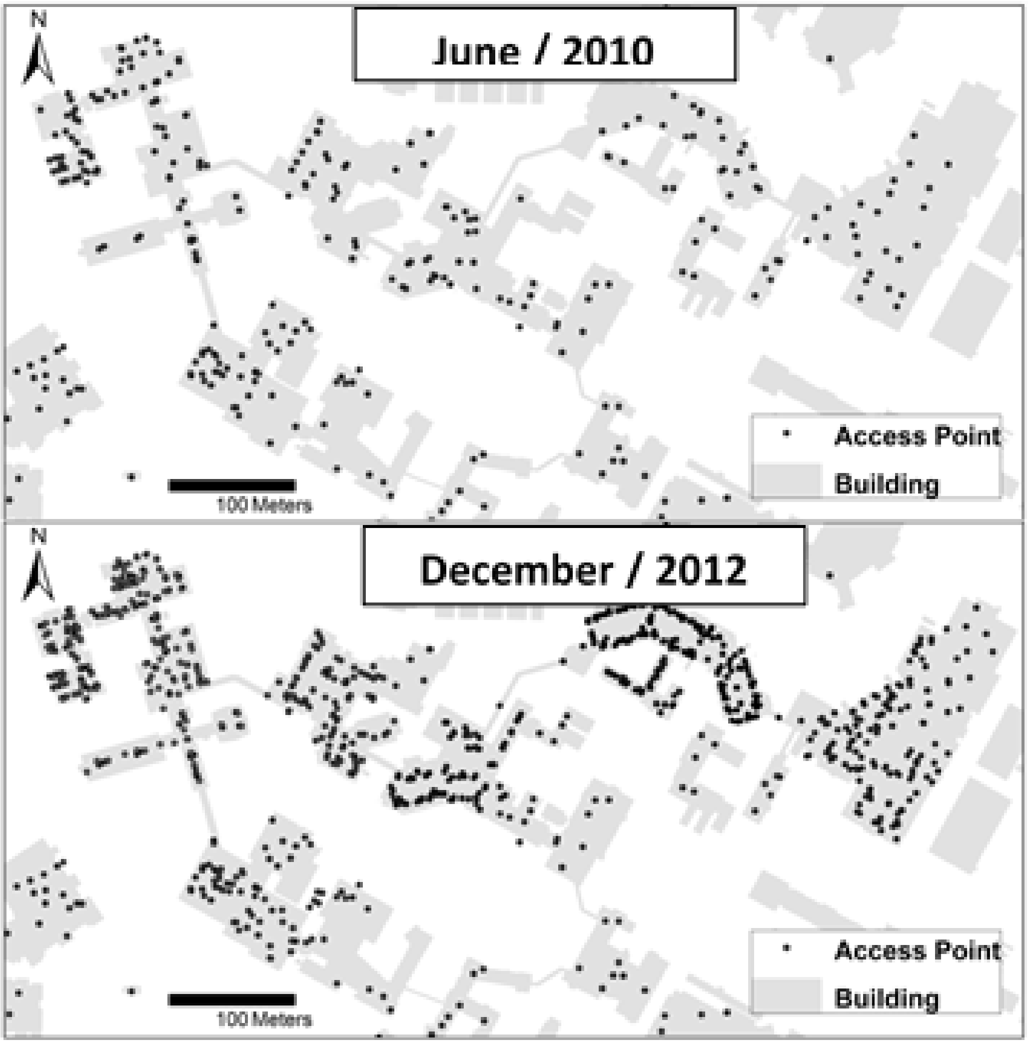

Figure 3.3 Available APs in the core part of campus in the University of Saskatchewan

To test positioning error under different AP densities, two campus buildings (Agriculture and Thorvaldson) were selected for which we have data both before and after the installation of new routers. 9 floors were tested, with a total of 225 random points (Figure 3.4). We were also interested in how positioning performance would be affected by movement. Therefore, a further investigation involved the testing of SaskEPS under dynamic conditions (i.e. tracking continuous movement) at the UofS campus (Figure 3.5). For this, the SaskEPS algorithm had been modified from Figure 3.2 for this tracking test (WiFi readings every 2 seconds instead of 10).

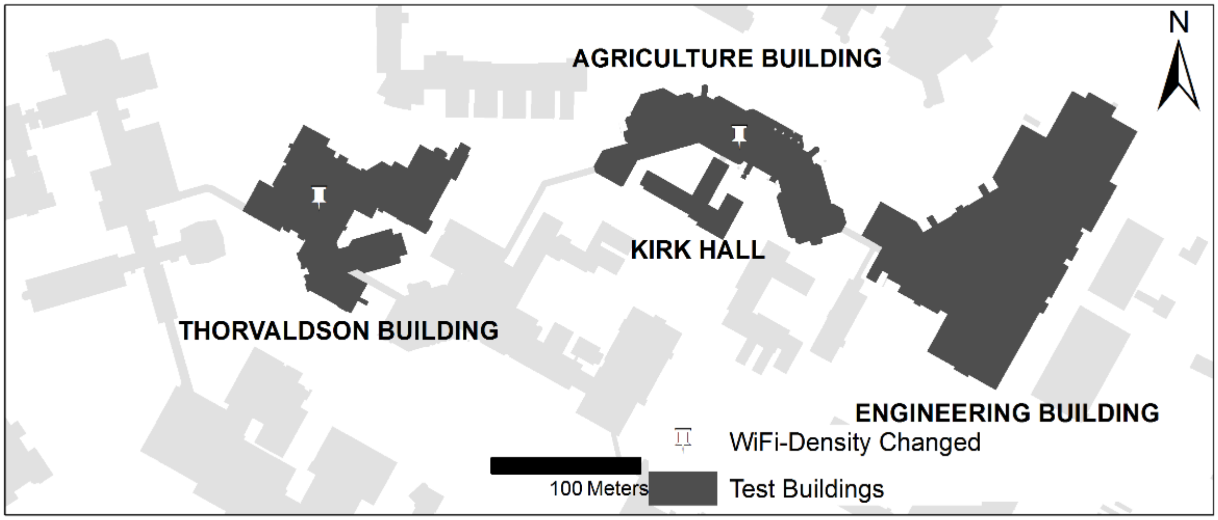

Figure 3.4 Tested campus buildings at the University of Saskatchewan

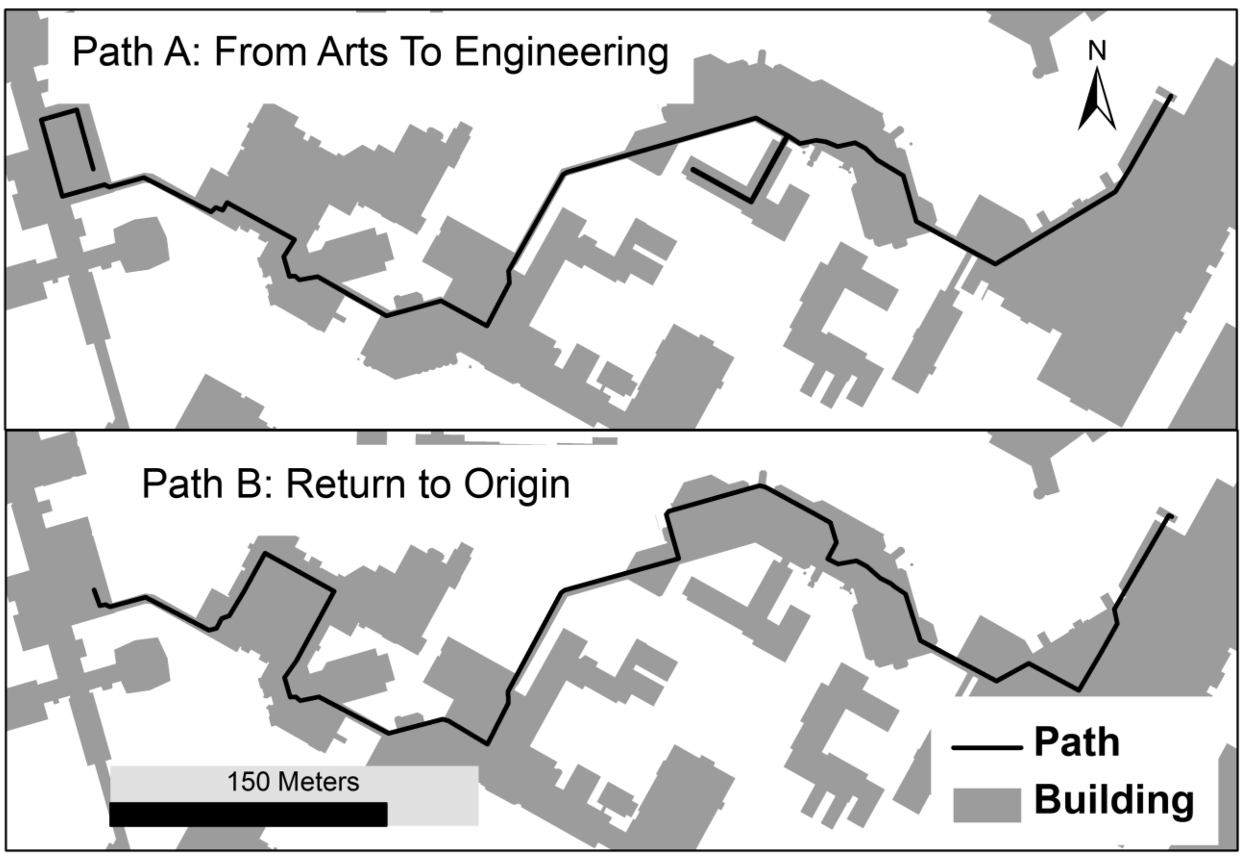

Figure 3.5 SaskEPS tracking experiment paths (Total 1972 meter; Path A: 1035 meter & Path B: 937 meter)

3.4 MEAN POSITIONING ERROR OF WPSs IN INDOOR ENVIRONMENTS

Studying the accuracy of WPS in indoor spaces will add value as a positioning reference to WiFi networks for spaces where GPS is not available. Initially, the efficiency of both most widely known/used commercial WPSs and SaskEPS were tested in indoor environments to identify which system was more accurate. The overall positioning quality of the iPhone's onboard positioning services was insufficient as a complement to GPS. These services resulted in high positioning errors compared to GPS (Figure 3.6).

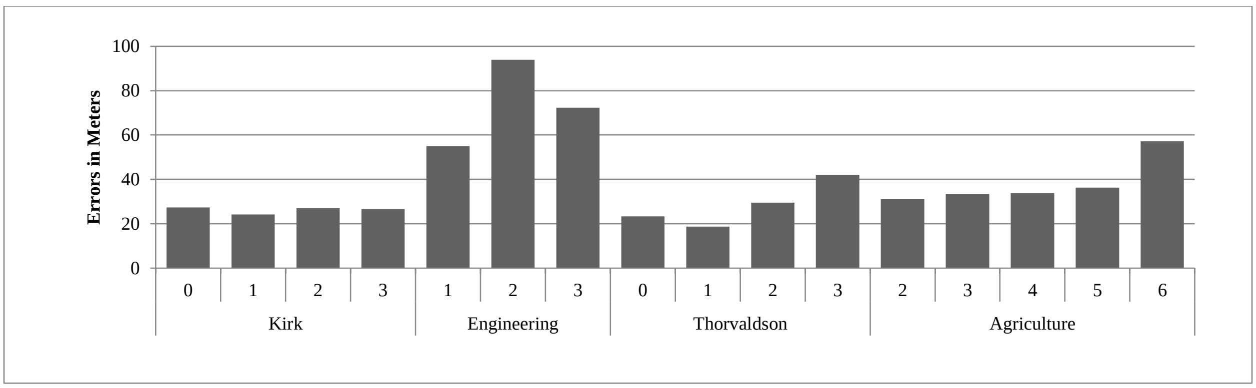

Figure 3.6 Mean indoor positioning errors for the iPhone's onboard WPS

The iPhone's mean indoor positioning errors were typically above 20 meters, and in some cases over 500m. In addition, iPhone indoor positioning results often indicated the user's location to be outside the building's footprint (Figure 3.7). This high location uncertainty has the potential to cause many problems for users (Lemelson, Kjægaard, Hansen, & King, 2009). SaskEPS successfully produced GPS-like mean positioning errors for most of this experiment's indoor environments (Figure 3.8).

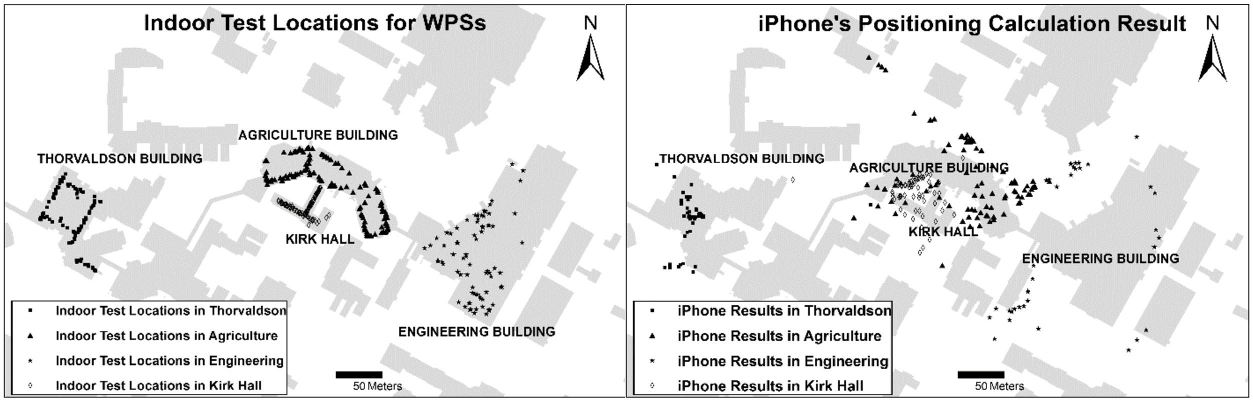

Figure 3.7 Calculated indoor positions with iPhone's WPS (On the top are the actual locations visited during testing, on the bottom are the locations calculated by the iPhone)

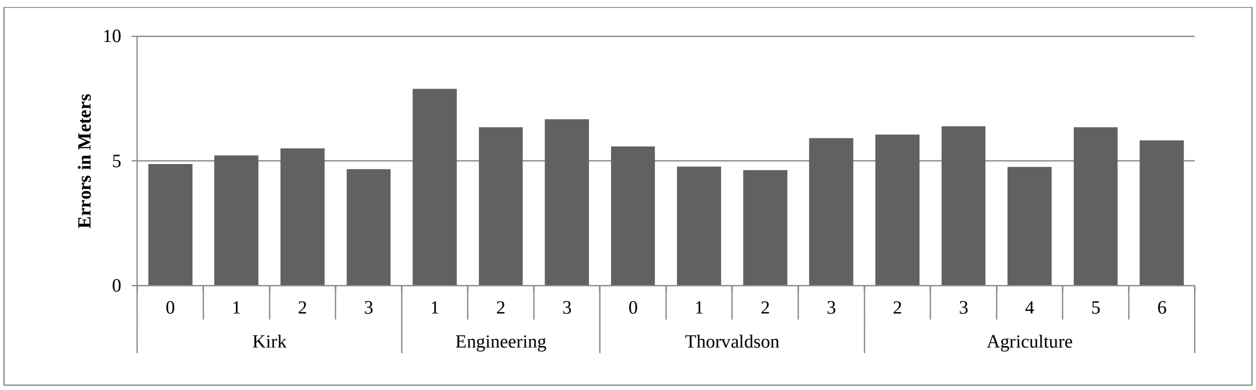

Figure 3.8 Mean SaskEPS's indoor positioning errors

Interestingly, both SaskEPS and the iPhone's onboard WPS indicated relatively high positioning errors in the Engineering building. This problem may be caused by the complexity of the building. The Engineering building has a very complicated floorplan compared to other campus buildings. SaskEPS's positioning reliability was also much better than the iPhone's onboard WPS. Most of the estimated positioning points were located along the correct hallway and buildings and included precise vertical (floor) information. This indicates that SaskEPS can provide GPS-like positioning service with high location certainty (Figure 3.9).

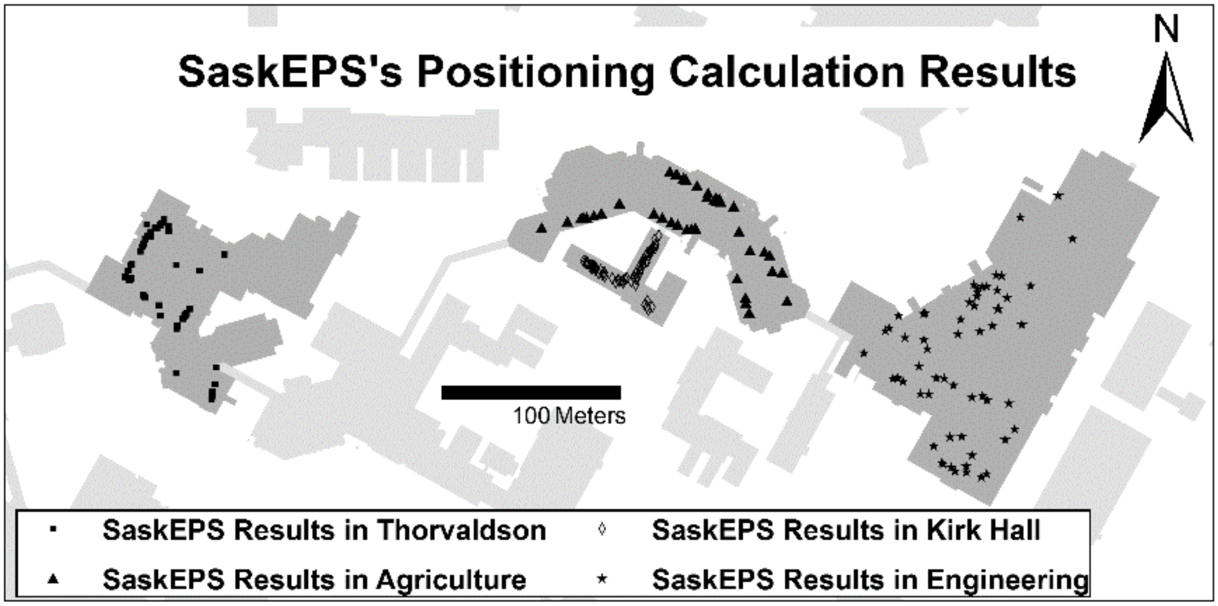

Figure 3.9 Calculated indoor positions with SaskEPS

Positioning accuracy varied based on the number of available APs, the arrangement of these APs, as well as building structure. SaskEPS successfully produced GPS-like indoor positioning service in the Engineering Building and Kirk Hall, but its performance became marginal in the Thorvaldson Building, and unacceptable in the Agriculture building. This inconsistent positioning accuracy may be caused by the difference in AP densities among buildings (Table 3.2).

Table 3.2 Positioning error and WiFi density of tested buildings

Building Name	APs Per 100m^2	Positioning Errors (Meters)	
		SaskEPS	iPhone
Kirk Hall	8.91	5.07	26.32
Engineering	4.09	6.97	73.77
Thorvaldson (Jan / 2010)	1.91	9.94	28.40
Agriculture (Jan / 2010)	0.79	17.87	38.37

In the latter two buildings (Thorvaldson and Agriculture), it is interesting to note that despite the reduced accuracy, all resulting locations were within the building footprint. Despite this, the range of errors is quite substantial and would be unlikely to support LBS or door-to-door navigation (Figure 3.10). This problem may be caused by a relatively sparse router array as well as the extensive areas in each building that do not have a line-of-sight router available. The trilateration algorithm requires an exact AP location for at least three routers (not all of which need to be line-of-sight) (Gallagher et al., 2009). This suggests that a minimum WiFi density may be required to produce seamless and continuous GPS-like positioning services for both outdoor (GPS) and indoor (SaskEPS) spaces.

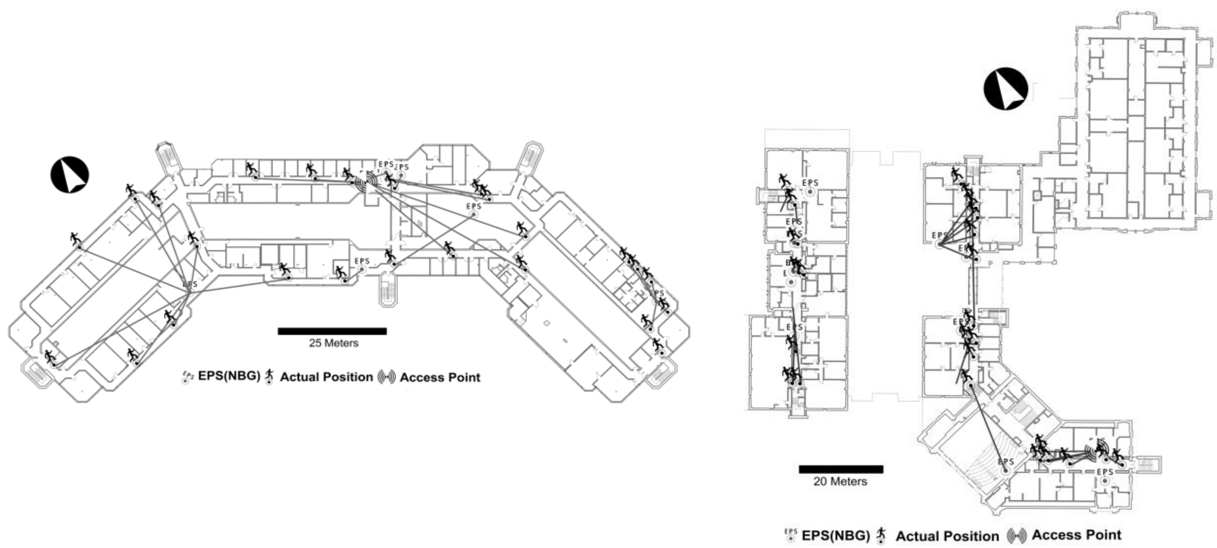

Figure 3.10 SaskEPS positioning calculation limitations in low-WiFi density environments (Top: Agriculture 6th floor and bottom: Thorvaldson 3rd floor)
**Line show matched result between actual position and calculated position*

3.5 THE RELATIONSHIP BETWEEN WiFi DENSITY AND SaskEPS POSITIONING ERROR

WiFi signal coverage is a critical component that should be validated before establishing any WiFi-based positioning system. Previous study suggested that more WiFi signal reference points promises better positioning result for the fingerprinting based WPSs (Li et al., 2006; Li, Wang, Lee, Dempster, & Rizos, 2005). On the other hand, SaskEPS's trilateration-based algorithm requires signals from at least three visible APs (receives a clear signal, but is not necessarily line-of-sight) from a user's position for nominal positioning determination. In addition, WiFi signal coverage validation is necessary for such a system to be viable in a specific area (Bahl & Padmanabhan, 2000). The efficiency of SaskEPS continues to be tested; however, our results also suggest that a threshold WiFi density is necessary for accurate WPS performance (including SaskEPS and WPSs) (Figure 3.11).

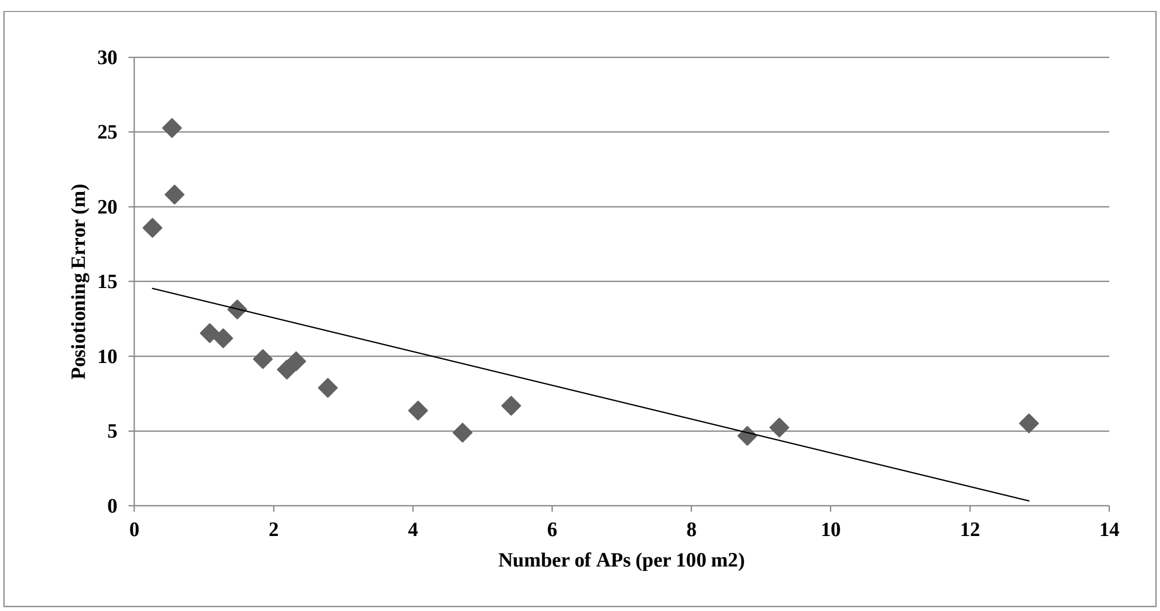

Figure 3.11 Relationship between number of APs and SaskEPS's positioning error (the average errors of all the tested locations: Correlation:-0.68)

Initial testing across several buildings and floors indicates that sub-10m positioning error for SaskEPS is achieved when more than 2 APs/100m^2 are available. If more than 8 APs/100m^2 are available, SaskEPS is capable of producing indoor positioning service with sub-5m positioning error. In other words, if more than 2 APs/100m^2 are available, SaskEPS provides GPS-like positioning services indoors. Furthermore, increased WiFi density helps to provide more accurate positioning services. In contrast, there is no significant change in positioning accuracy based on increased WiFi density when using Skyhook Wireless or Apple Inc. (Figure 3.12). These services result in average positioning errors between 20 and 30m in both low and high WiFi density environments. There is no correlation between WiFi density and indoor positioning errors for these competing services.

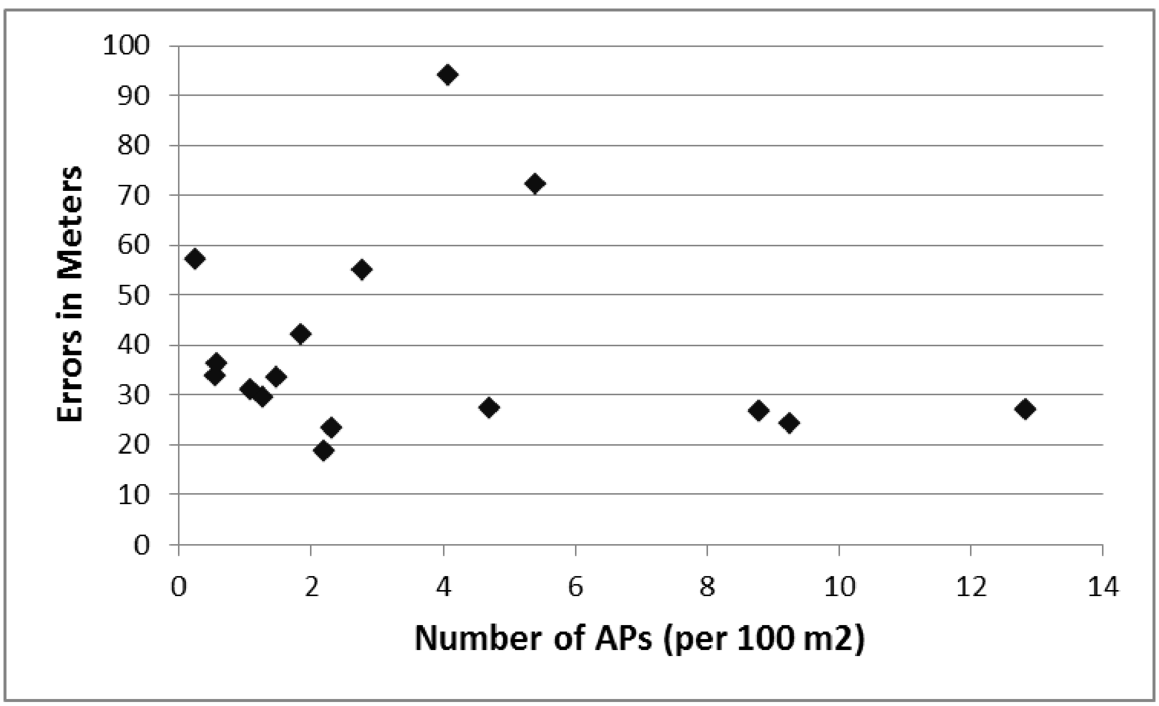

Figure 3.12 Relationship between number of APs and iOS-based WPS's positioning error

Our results indicate that the overall positioning accuracy of SaskEPS is dependent on WiFi density in the buildings tested, however we are unable to show the impact of different WiFi densities on positioning accuracy in a single building (see Table 3.2). To verify the relationship between WiFi density and positioning accuracy while controlling for building structure, two campus buildings (Agriculture and Thorvaldson) were tested before and after the router array was upgraded. The first test was conducted with a relatively coarse AP array (before January 2010) while the second test was conducted with an updated (and denser) AP array (after December 2012). AP densities in both the Agriculture and Thorvaldson buildings increased by more than 300% during that interval.

In all settings an increase in WiFi density resulted in a corresponding increase in positioning accuracy. There was some improvement in accuracy for the iPhone, however it did not approach sub-10 meter error and continued to place several locations outside building footprints (Figures 3.13 and 3.14).

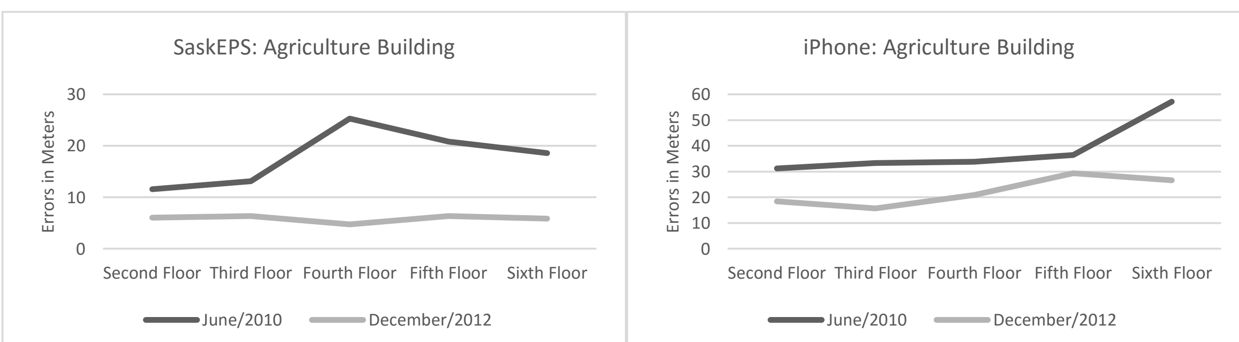

Figure 3.13 Overall positioning error shift in different WiFi densities for Agriculture building

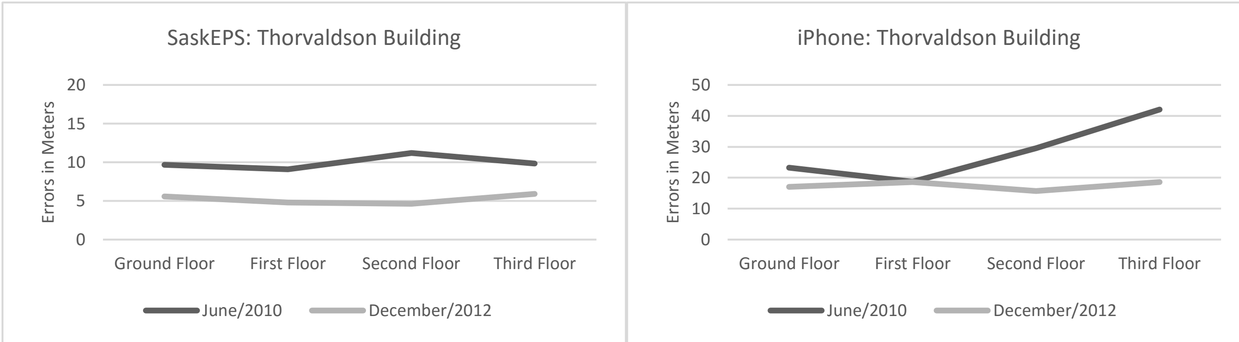

Figure 3.14 Overall positioning error shift in different WiFi densities for Thorvaldson building

For SaskEPS, the level of positioning error and WiFi density are highly related, because WiFi density factors do play a role in accuracy. Above 4 APs/100m^2, positioning accuracy is influenced more by building structure than WiFi density (Figure 3.15).

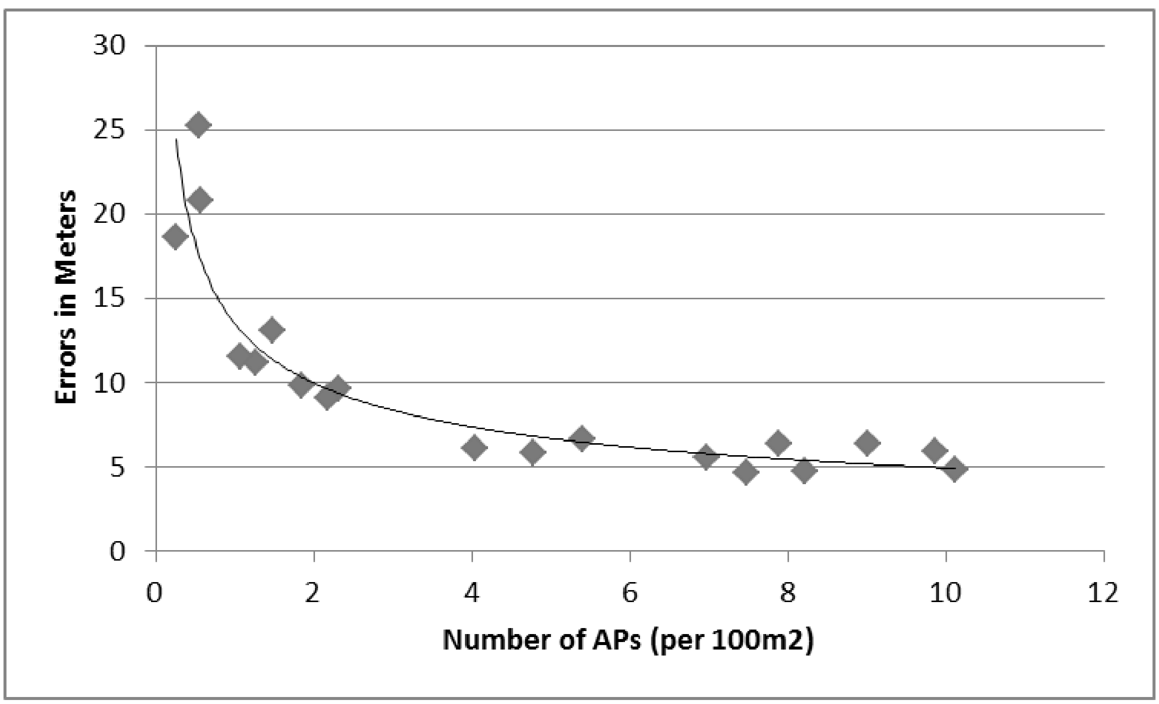

Figure 3.15 Relationship between number of APs and SaskEPS positioning error in Agriculture and Thorvaldson

Figure 3.15 indicates that when WiFi density reaches then exceed 4 APs/100m^2 SaskEPS's positioning accuracy shows minimal improvement. While SaskEPS is able to produce positioning results with accurate X-Y coordinate and vertical (floor) information, the latter appears more sensitive to WiFi density (Figure 3.16).

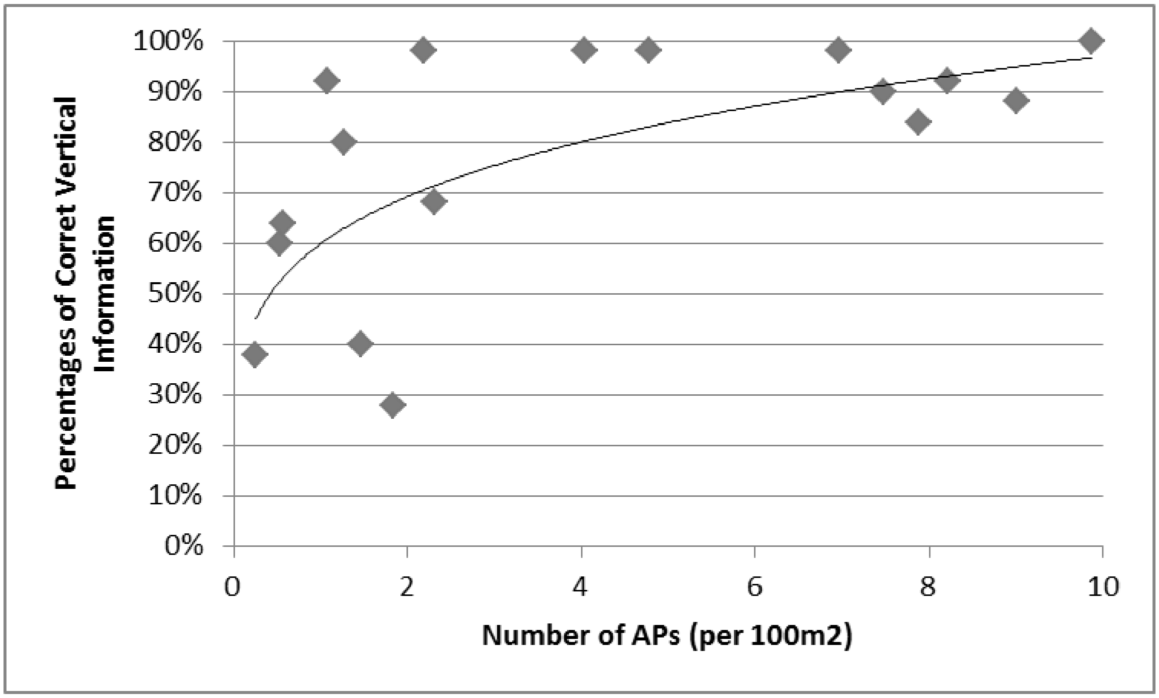

Figure 3.16 Relationship between number of APs and SaskEPS's vertical information accuracy in Agriculture and Thorvaldson (vertical accuracy is based on the percent of test locations on a floor that are correctly placed on the correct floor)

SaskEPS determines vertical information based on matching the strongest line-of-sight AP signal and AP-survey information in the database. If WiFi density is low, SaskEPS becomes a 2D system only, like other commercial WPSs, as SaskEPS may only provide accurate vertical information 50% of the time. In contrast, when WiFi density increases, floor information accuracy improves (above 85% of test locations). Figure 3.16 indicates that if WiFi density is low, SaskEPS no longer produces 2.5D positioning services. As a result, higher WiFi density improves not only

2D positioning accuracy but also increases location certainty in multi-story environments. Relatively dense AP arrays (> 4 APs/100m^2) are required for SaskEPS to produce GPS-like positioning service in multi-floor indoor environments.

3.6 DYNAMIC POSITIONING OF SaskEPS

Additional benefits of dense WiFi arrays are that SaskEPS may be used for real-time tracking or navigation assistant. To establish a true GPS-like positioning service and turn-by-turn navigation assistance is required for SaskEPS. Turn-by-turn indoor navigation assistance will maximize the usability of SaskEPS for indoor navigation. To test the efficiency of SaskEPS's turn-by-turn navigation assistance, a SaskEPS-enabled device's continuous movement was tracked. This experiment helps evaluate whether or not SaskEPS can be used as a real-time navigation assistant tool. This SaskEPS tracking experiment was conducted in several campus buildings at the University of Saskatchewan campus. The result of these indoor navigation tracking experiments proves that SaskEPS has potentially extended its dynamic positioning functionality to support turn-by-turn indoor navigation assistance (Figure 3.17).

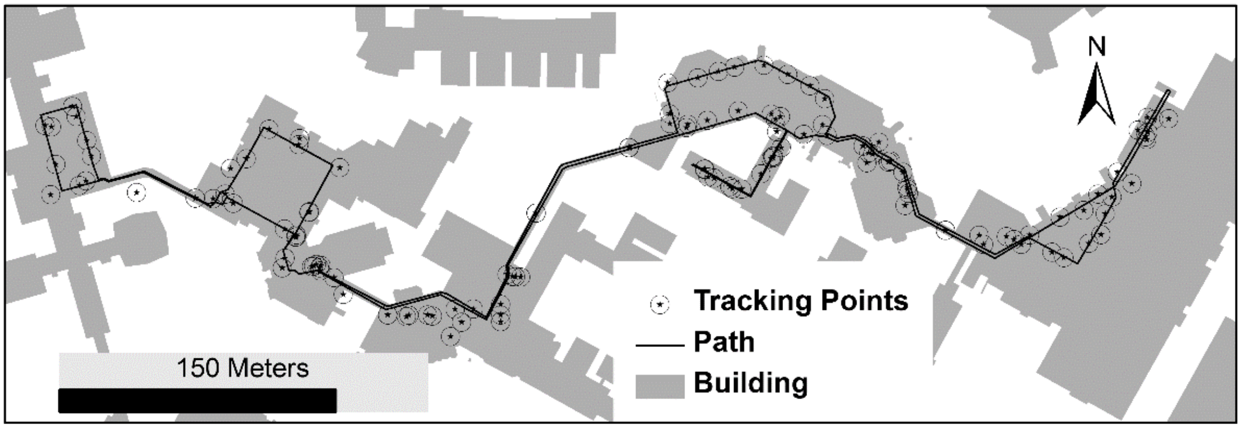

Figure 3.17 SaskEPS tracking experiment result

Several challenges must be overcome before establishing turn-by-turn indoor navigation services with SaskEPS. Most dynamic positioning results are located along the experimental paths by chronological order but there are some missing calculations in the positioning results. Total navigation time for this experiment was 33 minutes (1980 seconds). As a result we expect 198 tracking points as the tracking algorithm is set to 5 signal scans every 10 seconds (1 scan/2 seconds). Our results indicated 154 successful tracking points (78% successful calculations). This problem may be caused by technical delays or a failure to locate validated APs for a single location's calculation. A distinct pattern emerges when calculated tracking points are mapped with campus buildings and the predetermined path. The majority of the dropped tracking points are located along indoor bridges that connect buildings on campus (continuous indoor navigation among buildings). Bridges are linear locations that do not support the deployment of a dense AP array. Incorporating this information could improve tracking results. Tracking results couldn't be evaluated same as other SaskEPS positioning result because we do not know where SaskEPS estimated current location while it was moving. Tracking results were evaluated based on two major elements: 1. Tracking results were on the path or not, and 2. Chronological order tracking results was matched with moving direction or not.

3.7 DISSCUSSION AND CONCLUSIONS

GPS significantly contributes to UPS by delivering location information in real-time in almost all outdoor settings (Steiniger et al., 2006). GPS has made a significant contribution to the improvement of LBS; however, the GPS-based LBS is quite limited in indoor spaces due to the inability of weak GPS signals to penetrate building walls. Many commercial WPSs have been introduced but tend not to satisfy users and supplementary systems (LBS and navigation, for instance) that have come to expect GPS-like positioning accuracy. In order to better satisfy users, SaskEPS takes a “bottom up” approach to developing a GPS-like WPS.

From the perspective of SaskEPS and other trilateration-based WPSs, the quality of the WPS database is one of the most important components necessary to deliver GPS-like positioning services in indoor environments. Furthermore, SaskEPS employs a multi-scheme positioning algorithm for location determination rather than a fingerprinting approach. SaskEPS employs the trilateration method to determine X-Y positioning for two major reasons: first, trilateration has the added strength of managing nominal (and relatively minor) changes in the database component of the system. Once SaskEPS is established with a well-developed database, it can provide positioning services even if some APs are eliminated or replaced (as long as the nominal requirements for trilateration are still met). While the positioning accuracy may be lower until the WPS database is updated, it can be accomplished with less effort than the fingerprinting method (Bell et al., 2010). Second, SaskEPS has the advantage of initially working with a partner who has the sole authority to install and maintain routers, making the preparation of our initial database of router point locations much easier and more conducive to trilateration.

SaskEPS successfully produces GPS-like indoor positioning services in the core campus section of the University of Saskatchewan. However, previous studies indicate that SaskEPS and other WPSs needs to integrate testing and experimentation under different conditions to establish the nominal and optimal conditions for better positioning (Jung et al., 2012). If WPSs are established in high WiFi density environments, the impact of other sources of error can be reduced; this includes WiFi-signal multipath, the impact of which has not been established. The multipath effect poses potential risks which may increase SaskEPS's (and other WPSs) positioning error and reduce reliability even in high WiFi density (number of APs / 100m^2) environments; therefore, towards a better understanding of WiFi signal attenuation patterns and multipath effects, WPSs can produce more seamless positioning services with consistent positioning error in various indoor environments.

Although SaskEPS and other WPSs still need to overcome some obstacles for secure indoor positioning services, SaskEPS is capable of extending UPS (including turn-by-turn navigation support) and LBS to other indoor environments where WiFi services are available with adequate density. In locations such as airports, major hospitals, shopping malls, university campuses, terminals, and subway stations, SaskEPS would greatly increase convenience for both visitors and regular users. Secure and reliable indoor positioning systems can provide great benefits for our indoor activities as a major portion of our daily activities are primarily placed indoors. WPSs have a lot of potential to become a complementary positioning source indoors. Many studies have already been conducted for investigating the effectiveness of WPS under a variety point of view. It would be important to define an acceptable level of positioning error for indoors, or consider other aspects which may improve indoor positioning services. Although accurate indoor positioning is important, human experience with these services should be investigated as an additional factor.

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CHAPTER 4

POTENTIAL RISKS OF WiFi-BASED INDOOR POSITIONING AND PROGRESS ON IMPROVING LOCALIZATION FUNCTIONALITY[2]

4.1 INTRODUCTION

Successful navigation is one of the essential requirements of human survival and our contemporary daily lives. The ability to successfully navigate among multiple destinations and return to an origin (home) is central to procuring the necessities of life (food, water, shelter, etc.). It can be concluded that successful and efficient navigation is a critical issue. Human navigation is highly dependent on the accuracy and completeness of our cognitive map. Despite this, humans do not always have complete spatial knowledge of the places through which they normally navigate; therefore we have developed various methods to share it and adapt to its absence (Golledge, 1999). Maps and verbal communication, which are most widely used for delivering this type of information, play major roles in conveying geographic and spatial knowledge (Ishikawa, Fujiwara, Imai, & Okabe, 2008), although new methods are emerging.

Recent advances in location finding and smartphone technologies can deliver spatial information beyond conventional methods. These technological advances have put a wealth of

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both enriched and real-time geographic information in the palm of our hands. Our spatial behaviours, especially navigation performance, can now be supported and improved with accurate location information including distance and turn-by-turn directions along routes via multiple modes and purposes of travel. These advances help us to navigate through novel environments instantly and efficiently, as GPS-based navigation systems deliver accurate location information. Many technological contributions have been made to increase the positioning accuracy and consistency of GPS-based navigation systems (Taylor, Blewitt, Steup, Corbett, & Car, 2001), however current GPS-based navigation systems are still limited in certain environments. This typically results in a dearth of support for navigation problems indoors.

While indoor navigation might be associated with shorter travel distances and decreased travel time, it may represent a greater challenge as a result of differences in structural complexity and reduced field of vision. It is possible that these challenges can be overcome with precise graphical or verbal directions (Pradhan, Ergen, & Akinci, 2009); however, many people tend to have more difficulty navigating unfamiliar indoor environments than unfamiliar outdoor environments due to their complexity and irregularity (Meng, Dodson, Moore, & Roberts, 2007). Furthermore, indoor spaces usually have a generic configuration and lack unique spatial features, making it difficult to become quickly familiar with the environment. Finally, we spend much more time indoors (over 75% of our time) than outdoors (Klepeis et al., 2001). All of these characteristics of indoor navigation suggest that a navigation system tailored to indoor space might provide greater value than GPS-based systems are able to provide outdoors. In order to expand navigation-based technologies to indoor environments, we first need an accurate and reliable positioning system.

This paper is focused on providing entry level information about potential risks in any WiFi-based or other radio beacon based indoor navigation systems. Investigating theoretical or conceptual problems are very critical for any scientific endeavor; however, as geographers we tend to focus on the problems in physical space. This research evaluates factors (and scale of impacts) that influence WiFi-based Positioning System (WPS) indoors. This paper connects the theoretical model of WPS indoors and real world problem solving, in the form of navigation.

4.2 INDOOR POSITIONING SYSTEM

Presently, GPS-based positioning systems deliver reliable positioning information and are integrated with Location Based Services (LBS) in most outdoor environments; however, similar services are not available indoors due to the absence of accurate and reliable positioning sources (Borriello, Chalmers, LaMarca, & Nixon, 2005; Zandbergen, 2009). Our modern lifestyle is rapidly becoming occupied by information technology and our demand for more geographically "smart" information is growing. GPS allows users to obtain positioning information easily, but presents its own set of weaknesses. First, GPS usually does not work properly indoors because the GPS signal is susceptible to interference and can be blocked by structural features. Second, conventional GPS requires a specific device for acquiring positioning information from GPS satellites. As mobile devices become more advanced (decreasing size, increasing computing power, additional sensors, etc.) and are becoming increasingly popular, the demand for universally available positioning systems and LBS in all environments has increased (Raper, Gartner, Karimi, & Rizos, 2007). In addition, if indoor positioning services are provided through mobile devices, these systems should produce indoor positioning with available sensors with little or no additional hardware (Feng, Au, Valaee, & Tan, 2010). As a result, many WPSs have been established to provide trustworthy and complementary indoor positioning services toward the development of a truly Ubiquitous Positioning System (UPS). WiFi is one of the key sensors found on most mobile devices so it is a cost-efficient solution for indoor positioning (Meng et al., 2007). WPS is a value-added extension of the WiFi-network. In particular, WiFi positioning accesses the beacon signal that is available without authentication. Furthermore, most WPSs are software-based applications that can be deployed on different Operating Systems. These WPSs can be used to explore aspects of indoor positioning and the extension of such positioning to various value-added applications.

4.2.1 WiFi-based Positioning System

Many large scale WPSs are already available to the public (Google, Apple, etc.) and can be used easily with many popular mobile devices (notably smartphones), however these systems require significant improvement if they are to support both indoor positioning and navigation with GPS quality. Most WPSs compare WiFi-readings at a current location with WiFi information (signal strength, router identifier, etc.) held in a database. The WPS database is designed to provide the necessary information to the positioning algorithm in order to determine a current location; therefore the WPS algorithm continuously compares what is sensed in the environment with information held in the database. Current publicly available WPSs (no specific hardware requirement and availability of free public use), such as those available on the iPhone and Android smartphones, provide services for wide areas. Such WPSs have many limitations, primarily concerning the necessary information from the WPS database that it uses for establishing position (Bell, Jung, & Krishnakumar, 2010). Depending on the algorithm used, these databases contain the Media Access Control (MAC) address of each Access Point (AP) with accurate location or WiFi-fingerprint (WiFi-Radio map) information (Soonjun, Promwong, & Cherntanomwong, 2009; Tippenhauer, Rasmussen, Popper, & Capkun, 2009). Most WPSs utilize source data that is collected via unreliable, unstable, and insecure methods that attempt to build a WPS database with an emphasis on ease and efficiency of data collection (Tippenhauer et al., 2009).

The fingerprinting method is commonly used for many publicly available WPSs. This method reads current Received Signal Strength Indication (RSSI) at regular locations from a gridded layer of the radio signal map to then determine the location based on finding a matching RSSI in the WPS-database (Bahl & Padmanabhan, 2000; Shin, Jung, Yoon, & Han, 2011). If the WPS-database is not kept up-to-date, both Type I (false positive) and Type II errors are possible. Type I errors occur when the array of signals a mobile devices detects, matches a record in the database but that location is not the device's current location. A type II error occurs when the array of signals (and RSSIs) detected by a mobile device does not match any record in the fingerprint database (Watts, Brunger, & Shires, 2011). For this reason, fingerprinting-based WPSs often employ individual optimization processes for sorting reliable information in the database. Unfortunately, these database optimization processes are rarely clarified (Bell & Jung, 2010; Watts et al., 2011).

4.2.2 The Saskatchewan Enhanced Positioning System

Most smartphones provide indoor positioning services that have been significantly improved since 2011, when we first tested Apple's iOS 4.x. Recent Apple and Android systems show fewer outliers (over 100m error) or outdoor positioning results; however both Apple and Android systems are far from being competitive indoor positioning sources (Table 4.1). We are concerned that this high positioning error is caused by coarse WPS-databases as Apple and Android systems attempt to cover equally large indoor and urban areas but are struggling to establish and maintain accurate and up-to-date WPS-databases.

Table 4.1 Comparison of iOS 4.x, iOS 5.x, and Android indoor positioning system

Region	iOS 4.x (2011)	iOS 5.x (2012)	Android ICS (2012)
1	25.4 m	20.1 m	25.6 m
2	74.5 m	16.6 m	28.5 m
3	18.6 m	9.9 m	24.4 m
4	23.9 m	21.6 m	55.5 m

The Saskatchewan Enhanced Positioning System (SaskEPS) is designed to provide GPS-like indoor positioning in areas where indoor positioning contributions would be the most beneficial. SaskEPS can be distinguished from other WPSs and alternative indoor positioning systems in the following ways. Specifically, SaskEPS is designed for deploying a WiFi-based indoor positioning system quickly and remotely. Once the database is established, SaskEPS can start its positioning services with minor calibration based on the wireless router types or manufactures. This data is used for creating the WPS database. For this reason, SaskEPS only covers limited indoor locations but promises better indoor positioning through the most reliable WPS-database and the optimized location determination algorithm for indoors.

SaskEPS is a WPS that is implemented and designed with inspiration from a GPS standpoint that is both functional and systematic. SaskEPS employs both concise fingerprinting (location profiling) and trilateration (pin-point positioning) methods for the location determination process. First, for location profiling, SaskEPS determines a user’s nominal location (such as building or section names) and vertical (floor) position by leveraging each AP’s detailed location data. Second, SaskEPS converts RSS to distance for each sensed AP and uses these distances to trilaterate the location of the user (an important difference from the fingerprinting method described above). SaskEPS produces 2.5 dimensional positioning (X, Y coordinated and nominal floor information). For this reason, SaskEPS’s overall positioning error is highly dependent on individual AP information in the database (accurate geographic location and MAC address) and a number of APs in the region (Bell et al., 2010). The SaskEPS database is built and maintained using precisely surveyed AP information. It constructs the database with the goal of collecting AP information as accurately and thoroughly as possible. SaskEPS has shown that it can support reliable WiFi-based indoor positioning with decreased error using the rigid database (Bell et al., 2010). SaskEPS produces indoor positioning with sub-10m error, on average (Table 4.2).

Table 4.2 SaskEPS average error in 2010

	Region 1	**Region 2**	**Region 3**	**Region 4**
Average Error	5.07 m	6.97 m	5.23 m	5.88 m

** Each region value is the average error of 25 locations (SaskEPS shares same 25 location for the testing with commercial WPSs in Table 4.1)*

SaskEPS primarily employs a trilateration algorithm for location finding (Figure 4.1). SaskEPS's brief location determination process can be divided into four stages. First, SaskEPS identifies the closest and Line-of-Sight APs. Second, SaskEPS runs location profiling with limited use of the fingerprinting method to discover the AP with the strongest WiFi signal. SaskEPS then obtains both building and floor information from the WPS database for this AP. Third, SaskEPS determine accurate location of the device through modified trilateration method for SaskEPS. Finally, SaskEPS delivers user's 2.5D location with building name and floor. The distinguishing characteristic of the trilateration method is that unlike the fingerprinting method, it is not susceptible to inaccuracy caused by nominal changes to the AP-array/database (Bell et al., 2010). The similarity in positioning error (and sub-10 meter positioning error) of SaskEPS and GPS increases the usability and efficiency of LBS in both outdoor and indoor environments.

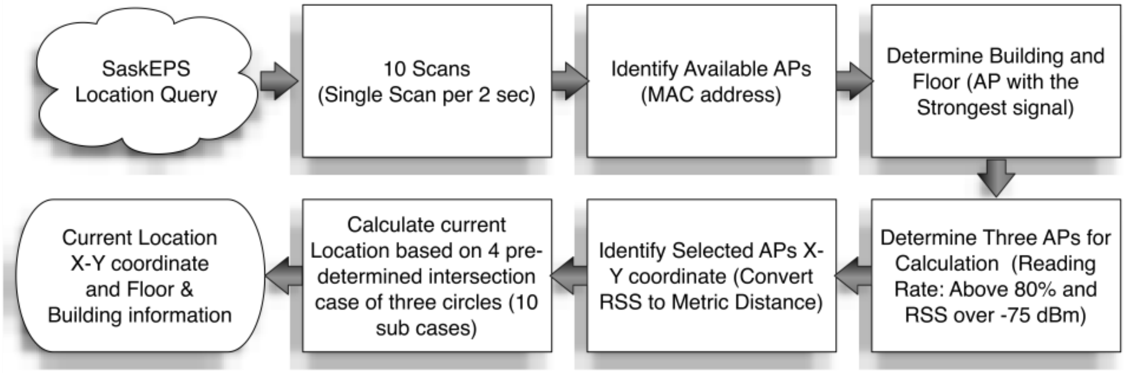

Figure 4.1 SaskEPS algorithm's brief workflow
**Reading rate represents successfully recorded RSS in single duty cycle (10 scans)*

4.3 DATA COLLECTION PROCEDURE

The University of Saskatchewan (UofS) provides a dense, publicly available WiFi-network. A complex, but mappable, array of APs covers the core area of campus and the number of APs has increased annually since 2010. All public WiFi APs are installed and the campus-wide array is maintained through a partnership between FMD and ICT. SaskEPS has been evaluated in four campus buildings, covering 16 different floors (Figure 4.2).

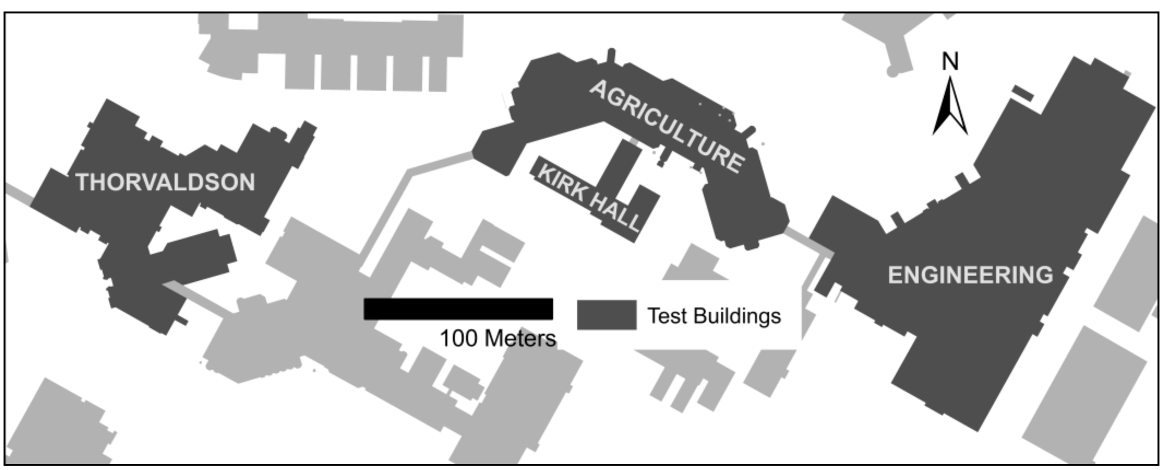

Figure 4.2 Four tested campus buildings at the UofS

Twenty-five random points were selected for each hallway on each floor (totaling 400 points). In 2010, these locations were visited and SaskEPS was used to locate a mobile device. More recently in 2011, new positioning results have been calculated from this original dataset to investigate the implications of using different signal reading methods (Maximum RSS vs. Mean RSS) for SaskEPS's location determination process.

4.4 CONSTRAINING ERRORS IN WiFi-BASED POSITIONING

Many indoor positioning systems, including SaskEPS, hold great promise as complements to GPS, however there are several potential sources of error. Most WPS positioning quality (overall metric error) is dependent on the availability of APs (WiFi-density). APs should be present above a nominal density in order to produce reliable indoor positioning. Most campus buildings at the University of Saskatchewan have adequate AP-density, with over 1800 APs across campus. Despite this, WiFi-based indoor positioning services can be interrupted by building layout and WiFi-signal characteristics such as multipath and signal attenuation (Bouet & dos Santos, 2008; Widyawan, Klepal, & Pesch, 2007). In order to maintain positioning quality, consistency, and certainty, potential threats or sources of interference should be considered.

4.4.1 Signal Multipath Effect

For GPS, multipath affects positioning accuracy by increasing error due to the delay in GPS-signal arrival time from what would be expected given the actual distance between a satellite and receiver (El-Rabbany, 2002). In these cases, error often appears when a GPS-device is used in either natural or urban valleys where GPS-signal is interfered with by elevated features. As well, any radio-signal is highly interfered with in most indoor environments because of unique indoor characteristics. Indoor positioning systems are more susceptible to signal multipath than GPS do to the greater presence of potentially intervening and nearby structural elements. Multipath will produce negative effects on most WPSs. It has a greater impact on trilateration-based WPSs than fingerprinting-based WPSs (Cheng, Chawathe, LaMarca, & Krumm, 2005). Most multipath events result in a multimodal RSS distribution (bimodal distributions are frequently observed): one mode for the direct path and one for the deflected/reflected path(s). Multipath makes RSS estimation difficult and introduces bias into the calculation of mean RSS for a given AP (Table 4.3).

Table 4.3 Mean RSS shifting based on multipath effects

Distance (Meters)	**KIRK AP #1**		**KIRK AP #2**	
	1st attempt	2nd attempt	1st attempt	2nd attempt
0	-30.2	-30.8	**-37.5**	-34.6
5	-31.9	**-45.5**	**-35.6**	**-35.9**
10	**-39.3**	**-37.3**	-36.8	-37.4
15	**-52.9**	**-51.7**	**-50.7**	***-63.7***
20	**-49.9**	**-55.0**	**-54.4**	**-54.3**
Distance (Meters)	**KIRK AP #3**		**ARTS AP #1**	
	1st attempt	2nd attempt	1st attempt	2nd attempt
0	**-35.0**	-30.0	-31.4	**-35.1**
5	**-35.2**	-30.6	-40.9	**-45.0**
10	**-47.9**	-30.8	-46.5	-49.5
15	***-65.5***	**-53.7**	**-61.3**	-58.1
20	-46.3	-49.5	-61.8	-60.8
Distance (Meters)	**ARTS AP #2**		**ARTS #3**	
	1st attempt	2nd attempt	1st attempt	2nd attempt
0	-33.3	-31.5	-30.5	-30.2
5	-32.0	-32.4	-30.5	-30.6
10	**-54.1**	-49.7	**-44.7**	**-43.7**
15	**-53.5**	**-55.8**	-50.9	**-53.6**
20	-54.1	**-54.0**	-46.4	-43.9

**"Distance" represents the distance between selected AP and SaskEPS (All values are dBm and Bold represent multipath effect)*

To investigate the multipath effect, we designed an experiment in which RSS values are recorded every 3 seconds over a period of 10 minutes using SaskEPS. In addition, RSS was collected twice at the same location. This approach allows us to establish evidence for multipath. In this test, when the same signal properties were present (multipath compared to multipath or two minor multipath distributions) there was not a significant difference in mean RSS (Figure 4.3).

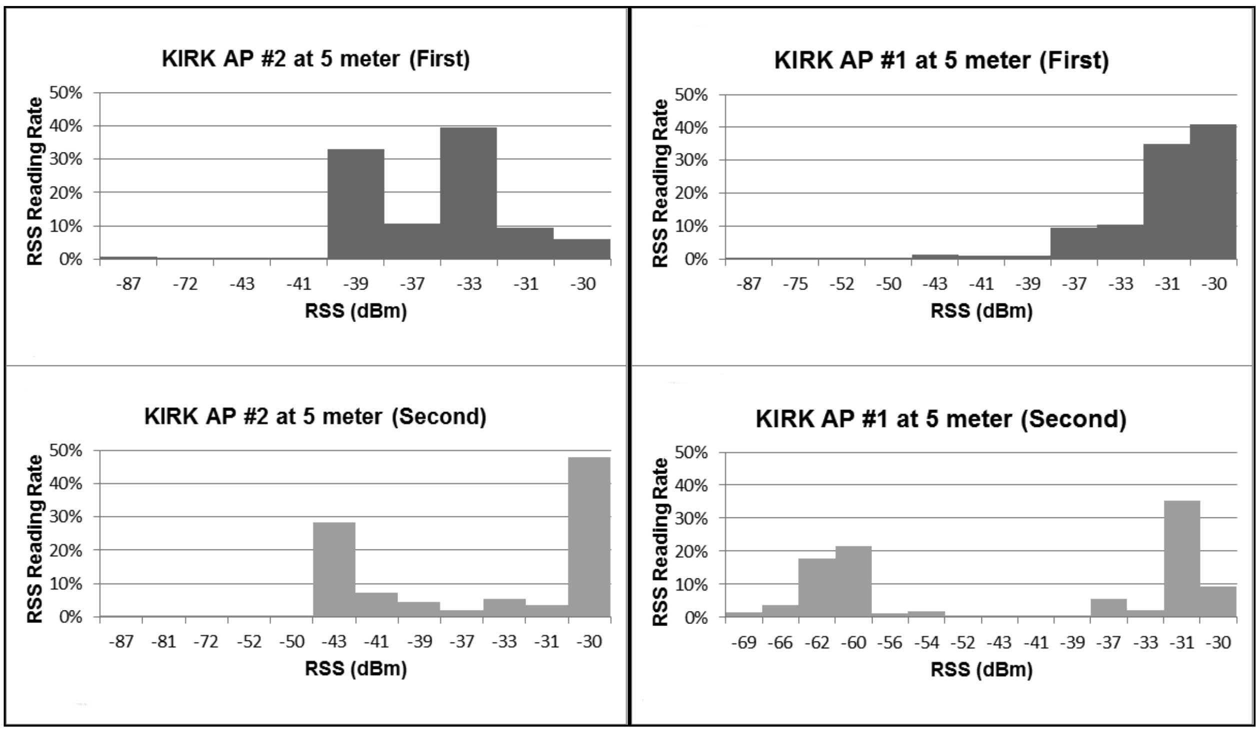

Figure 4.3 Signal reading variances by multipath effect (Left: Similar pattern of multipath effect (Average RSS: 1st -35.6 dBm and 2nd -35.9 dBm) and Right: minor multipath effect and a multipath effect (Average RSS: 1st -31.9 dBm and 2nd -45.5 dBm))
**This graph shows RSS reading distribution between Max and Min RSS*
***Y-axis 'RSS Reading Rates' represents the percentage of each recorded RSS readings for 10 minute (3 second intervals & total of 200 readings)*

When comparing whether or not multipath is present, there are distinct differences in mean RSS values (Figure 4.3). If only insignificant or weak multipath is present the mean and max RSS values do not differ substantially. When significant or strong multipath is present, the mean and max are more significantly different. SaskEPS shows very reliable positioning results in high WiFi-density environments, so if SaskEPS can reduce multipath, its positioning error should be reduced. One approach we have employed uses the max RSS instead of mean RSS for trilateration. When max RSS is employed, most positioning error measurements change but no significant improvement results (Table 4.4). In other settings, or with real world data, we believe trilateration using max RSS to be beneficial.

Table 4.4 SaskEPS average error difference between maximum and mean RSS

	Kirk	**Engineering**	**Agriculture**	**Thorvaldson**
Maximum RSS	**4.17 m**	**6.04 m**	**4.90 m**	6.62 m
Mean RSS	4.94 m	6.26 m	5.06 m	**5.86 m**

No significant difference between Max and Mean RSS result (Paired T-test: all p-value >0.05)

4.4.2 WiFi-Signal Variation

SaskEPS converts RSS to metric distance for location determination. When first deployed in 2009, SaskEPS calculated and used the mean RSS value of 10 distinct RSS readings from each "visible" AP for trilateration, including line-of-sight and non-line-of-sight. As a result, WiFi-signal attenuation is important when converting RSS to distance with measured RSS values for location calculation. Irregular signal strength can occur for a variety of reasons when using WiFi technology (network type, router strength, etc.) (Li, Salter, Dempster, & Rizos, 2006). These variations can generally be corrected through calibration. One nominal correction implemented in SaskEPS is to exclude weak WiFi-signals from the calculation process. Such signals (lower than -75 dBm) have a higher likelihood of being the result of severe attenuation or multipath. When signal strength is lower than -75dBm, successful reading rate of RSS in single duty cycle (10 scans) dropped to under 70% even if the WiFi-signal was from LOS-APs. SaskEPS only occupied reading rate that is above 80% for the calculation, so weak signal (lower than -75dbm) could be removed without further calculation.

4.4.3 Bracketing of WiFi-array

SaskEPS's positioning becomes unreliable at the edge of the WiFi array. For example, if a multi-floor building has low WiFi-density, SaskEPS may not retrieve enough APs to trilaterate a position or have access to a line-of-sight router for floor determination. In such a case, SaskEPS will fail to accurately determine the position or will calculate the position at the nearest AP (Figure 4.4).

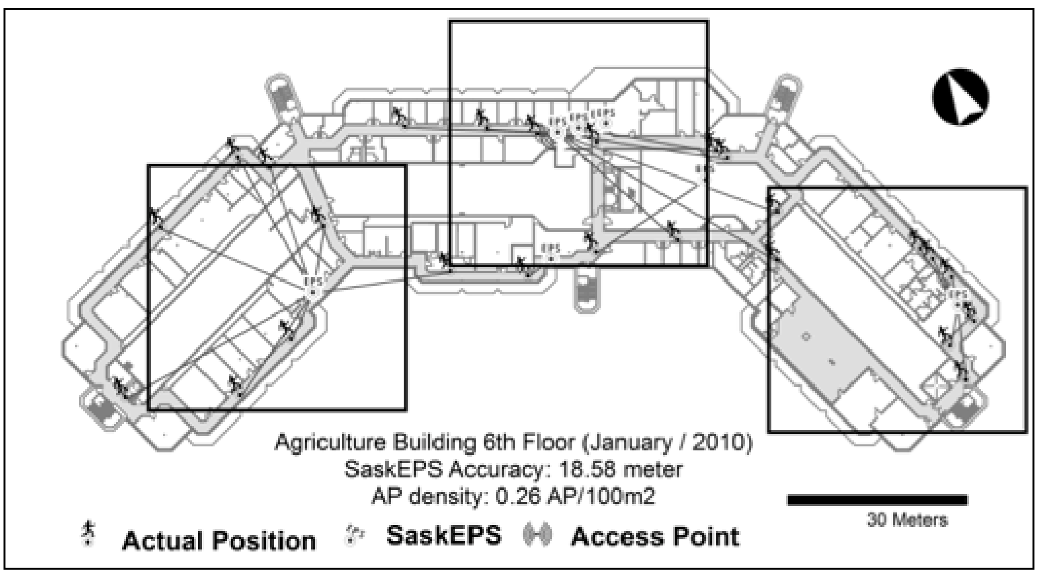

Figure 4.4 Positioning problems based on multi-floor buildings and WiFi-array structure (Agriculture Building 6th floor)

At the edge of the WiFi-array, trilateration would be based on sources that occupy similar hemispheric locations to one another, increasing the positioning error of the calculation. We find lower positioning error when a location is “bracketed,” or surrounded by routers. This is similar to the tendency of GPS to be more accurate in X and Y, rather than Z (El-Rabbany, 2002). All GPS satellites have a common orbital altitude, which reduces the variability among them along the Z axis from Earth’s surface; variability in the Z axis between GPS satellites and the surface is more consistent than the distance in the X and Y positions. These problems, when applied to SaskEPS, increase average positioning errors and decrease its positioning service reliability in specific areas.

4.4.4 Nominal Changes in the WiFi Network

SaskEPS has two major advantages in situations when the WiFi-network changes (new routers are installed or an existing router stop functioning). Any WPS should be prepared for any nominal change to a WiFi-network (Lloret, Tomas, Canovas, & Bellver, 2011). SaskEPS provides positioning services even if individual APs are eliminated or replaced, as long as the nominal requirements for trilateration are still met. While the positioning error may be higher until the WPS database is updated, such updating can be accomplished with less effort than the fingerprinting method (Bell & Jung, 2010). Second, SaskEPS has the advantage of working initially with a partner who has the sole authority to install and maintain routers, making the preparation of our initial database of router point locations much easier and more conducive to trilateration. A nominal change in a WiFi-networks’ array could cause some reduction in positioning accuracy (higher metric positioning error) but SaskEPS should not entirely fail to provide indoor positioning services even if some nominal changes appear on the WiFi networks.

4.4.5 Considerations for Technological Variances

Like many other beacon-based positioning systems, WPSs’ positioning results can be affected by technological variations in the hardware of both AP and mobile devices (Lui, Gallagher, Binghao, Dempster, & Rizos, 2011). RSSs at a similar distance can change based on devices used. In this case, accurate fingerprinting maps for all devices cannot be properly established because a calibration process is required for each device (Lui et al., 2011). Although SaskEPS and other trilateration-based WPSs convert signal strength to distance, some influences of technological variance can be allowed. For example, WiFi protocols (IEEE 802.11 b/g/a/n) have an impact on SaskEPS's distance estimates. For this study, two types of WiFi protocols (SaskEPS/A: 802.11 a/b/g and SaskEPS/N: 802.11 n/b/g) were used. SaskEPS produces lower positioning error when using SaskEPS/N than when SaskEPS/A is used. However when WiFi-density is higher, the difference between the two protocols is reduced (Figure 4.5).

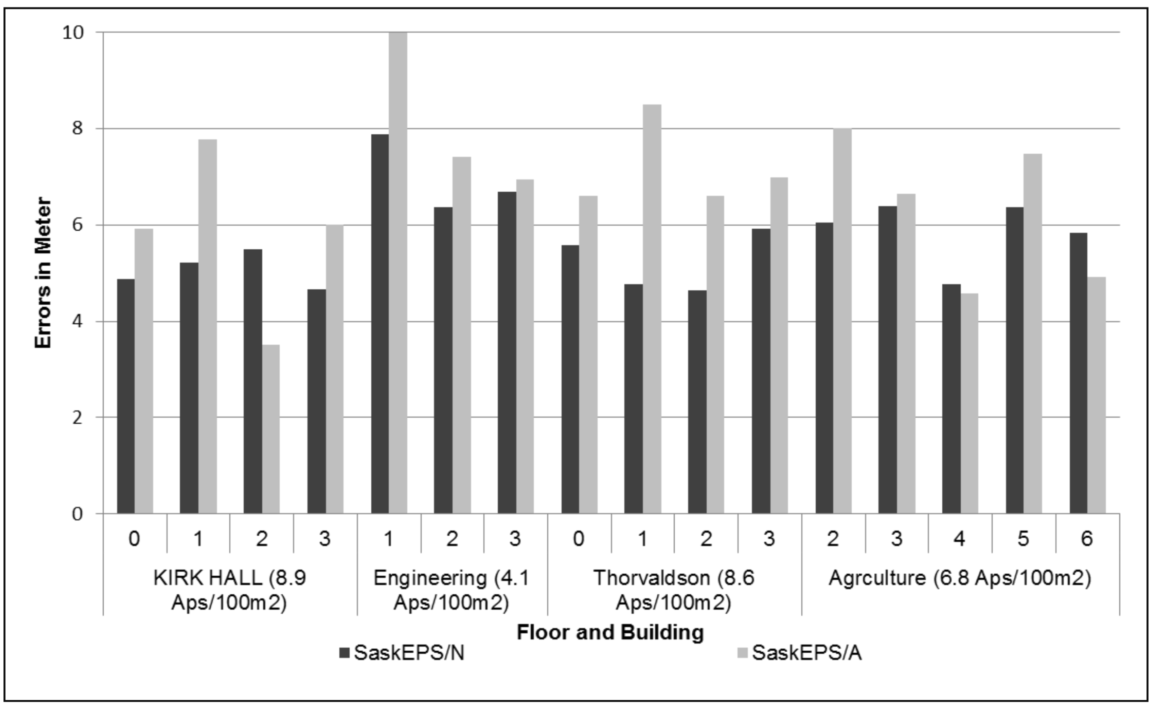

Figure 4.5 Technology variance of SaskEPS based on a different type of WiFi protocol

Furthermore, SaskEPS/N shows better location profiling, especially in regards to vertical information, over SaskEPS/A. In other words, low WiFi-density has a greater influence on positioning variance when relying on IEEE 802.11 a/b/g. Technological variances in the devices may cause some unexpected positioning result changes but these variances will not significantly reduce SaskEPS's positioning abilities. In addition, SaskEPS will be influenced less by WiFi infrastructure variance than other global scale WPSs. For this reason, SaskEPS is designed for bottoms-up installation is bounded areas and can make easy adaptations for each WiFi infrastructure's characteristics.

4.5 POSSIBLE FURTHER IMPROVEMENT

Most indoor spaces pose specific structural constraints on positioning and navigation (Bouet & dos Santos, 2008). For example, indoor spaces such as multi-story buildings consist of groups of cells (halls, rooms, stairwells, etc.), which are arranged both horizontally and vertically. Furthermore, these cells are either connected or disconnected from the entrance and other architectural components such as doors, floors, and walls, and the aforementioned halls, rooms, and stairwells. Corridors and stairs connect one destination to another; therefore, indoor navigation occurs predominantly along hallways. SaskEPS is designed to deliver door-to-door positioning information along hallways and usually shows sub-10m positioning error, although these positioning results usually contain nominally invalid results which are located outside of hallways and other publicly accessible spaces (the only test locations used were in such public spaces). An approach to remove this type of error and potentially improve meaningfulness of the positioning results is to introduce a method to constrain results to hallways. Most GPS-based navigation systems incorporate roads as linear features to which locations can be connected; the logic being that a car with a GPS-navigation system is likely on the road network and not in some space between road segments. In order to reduce high positioning error and increase positioning consistency and precision along linear routes, a map-matching method is used (G. Taylor & Blewitt, 1999). This method can help limit possible users' location in the hallways or road networks where a user can be or is allowed to be (Zhang, Wang, & Wan, 2003).

SaskEPS incorporates the CentreLINE network to correct invalid positioning results and to prepare SaskEPS expansion to a real-time navigation assistant along indoor routes. CentreLINE was created by converting the geometry of indoor corridors (polygons) to linear hallway features (lines). The navigable indoor spaces are categorized as corridors (hallways and stairs) and destinations (offices, class rooms, rest rooms etc.). If SaskEPS locates a user in a non-navigable space while a user is moving, this invalid location can be corrected with a map-matching technique based on the nearest logical location on the CentreLINE network (Jung, Bell, Petrenko, & Sizo, 2012).

4.5.1 Building CentreLINE Network

In a further attempt to increase accuracy and take initial steps towards the development of an indoor navigation system, we have built a network-based dataset of navigable indoor spaces for a continuous portion of a larger indoor environment. The walkable network inside buildings is generally constrained by building layout. With a detailed and georeferenced floorplan for a building (CAD drawings, blueprints, etc.), it is possible to model the walkable network by creating what we call a Walkable CentreLINE Network (WCN) (Figure 4.6). This network represents a continuous arrangement of lines (a network) that combines a set of points corresponding to the boundary of Voronoi polygons based on corridor edges. Furthermore, this approach allows for the construction of semantic WCN in open indoor spaces where no distinguishable barriers exist between corridors and rooms. Because semantic WCN could add contextual meaning to the odd navigable space where separated corridors are not available (Xiaohang, Dong, Chin, Hettiarachchi,

& Zhang, 2004). The purpose of the WCN project is to capture and simplify the geometry of the building layout to improve positioning and support indoor navigation.

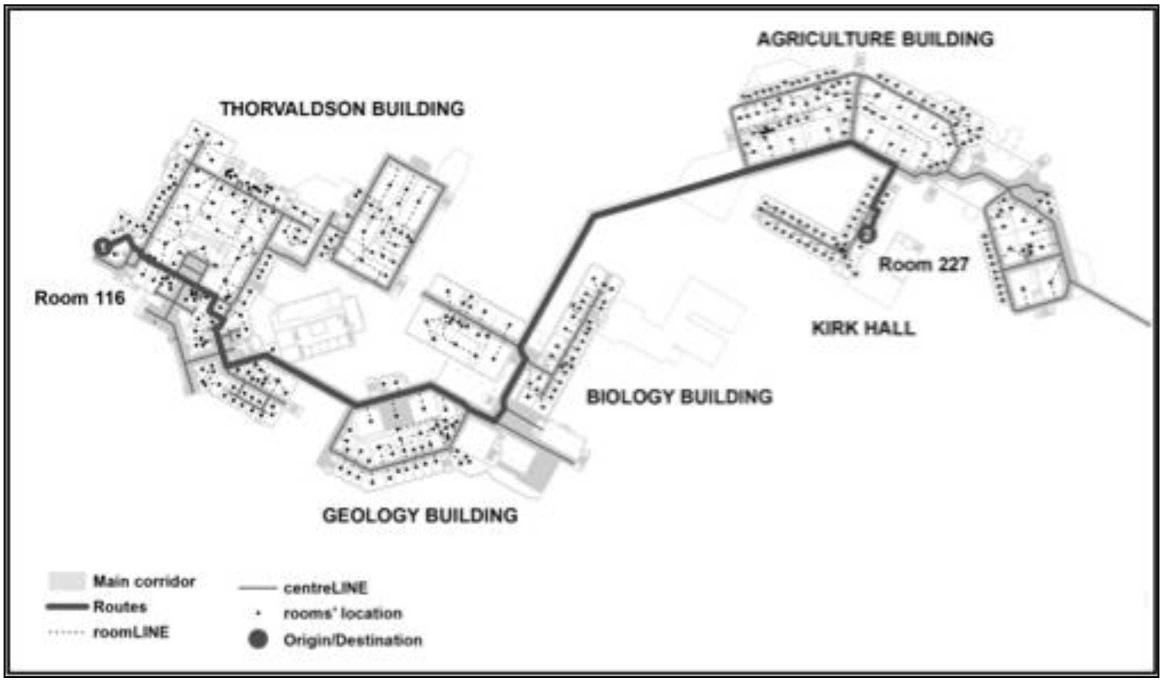

Figure 4.6 Generated the WCN with an example of door-to-door navigation

Building layouts do not always allow access to every room from a central corridor. Sometimes several "rooms" must be crossed to reach a final destination. To ensure proper door-to-door navigation, RoomLINEs are introduced. The primary CentreLINE feature connects all navigable hallways on a single building floor; a room's location is indicated with a point representing the centre of the room. A secondary set of lines is then introduced. RoomLINEs connect to corridors, and CentreLINE links rooms with their logical corridor according to their entrance position and adjacency. A CentreLINE with a set of secondary RoomLINEs and room positions is integrated in the WCN. By bringing together the various connected features that are necessary to navigate from one location to another, we can make several important contributions to indoor positioning and navigation. Generation of the CentreLINE WCN is fully automated and can be implemented using ArcGIS^{TM} model builder/scripts with minor manual adjustments.

In this application the introduction of the WCN is tested to examine whether it improves continuous indoor positioning by map-matching SaskEPS's raw positioning results to the closest perpendicular CentreLINE segments. The position of the user can be estimated by interpolating the positioning result from SaskEPS to the nearest point within the CentreLINE network. In addition, the trajectory formed by the most recent raw position can be used to determine which part of the building the user occupies and to provide a priori information on the next measured position of the individual. This is particularly useful for locations with unreliable WiFi signals and for which a previous position might be more reliable.

4.5.2 Map-Matching Method: Stay on the Meaningful Segment

One of the advantages of SaskEPS is its capacity to adapt applied technology from GPS in certain parts of the algorithm. Many people consider vehicle navigation systems to be accurate and reliable because a dot, which represents the vehicle's position, always stays on the road. In reality, an algorithm called "map-matching" forces the dot onto the road network or to the nearest network location, even if the actual GPS location is off the road network (Blazquez & Vonderohe, 2005; Mattos, 1993; Scott, 1994; George Taylor et al., 2001; Zhang et al., 2003). For this reason, vehicles are rarely displayed off-road (Jagadeesh, Srikanthan, & Zhang, 2004). SaskEPS's positioning results can be corrected in a similar fashion. For testing the efficiency of map-matching algorithm, the Stay on the Meaningful Segment (SMS) method has been applied to SaskEPS's previous positioning result (Maximum RSS). SMS "snaps" all SaskEPS's positioning results to the closest WCN segments (Table 4.5).

Table 4.5 Average positioning error comparison with and without SMS

	Kirk 2nd	Engineering 2nd	Agriculture 2nd	Thorvaldson 1st
With SMS	3.77 m	5.44 m	4.65 m	6.08 m
Without SMS	4.17 m	6.04 m	4.90 m	6.62 m

Initially we pooled all locations into our analysis (Table 4.6). An important characteristic of SaskEPS positioning locations (without SMS) is that most fall within the boundaries of the hallway network (where they nominally should be) while some fall outside the network. Some displayed locations are illogical (not in hallways, in locked rooms, etc.).

Table 4.6 presents results of pooled positioning (in and out-of-hallway locations together) that are separated into hallway and non-hallway categories. When raw positioning results were snapped to WCN, statistically significant improvement were found in SMS results. Interestingly and perhaps expectedly, when examining only out-of-hallway results, we see a significant improvement in accuracy, though in some cases, the average error for building increases. This suggests that the act of forcing out-of-hallway locations into hallways is a meaningful improvement to positioning results.

Table 4.6. Positioning quality improvement by SMS

	Kirk 2nd	Engineering 2nd	Agriculture 2nd	Thorvaldson 1st
All Positions	0.40 m**	0.60 m*	0.25 m*	0.55 m**
In-hallway Positions	0.08 m	-0.42 m	-0.38 m	-0.16 m
Out-of-hallway Positions	0.72 m	1.62 m	0.88 m	1.26 m

** P-values < 0.05 and ** P-values < 0.01 (Paired T-test)*
*** Negative values represent where positioning errors are increased*

4.6 DISCUSSION

Innovative technologies can contribute to the expansion of UPS and expand the value-added opportunities currently associated with GPS, such as navigation and wayfinding, LBS, etc. (Allen, 1999). GPS contributes to our spatial activities by delivering location information in real-time in almost all outdoor settings (Steiniger, Neun, Edwardes, & Lenz, 2008). GPS has made a significant contribution to the improvement of LBS, however the GPS-based LBS is limited to outdoor spaces due to the inability of GPS's weak signal to penetrate building walls. Many publicly available WPSs such as Apple's iOS™ and Google's Android™ have been introduced, but tend not to satisfy users and supplementary systems such as LBS and navigation that have come to expect GPS-like positioning accuracy. SaskEPS produces GPS-like indoor positioning in designated areas where indoor positioning will provide beneficial contributions. SaskEPS could provide more satisfactory indoor positioning services for those who expect to use seamless positioning services from outdoors to indoors with consistent positioning results.

SaskEPS successfully produced GPS-like indoor positioning services in a core campus section of the University of Saskatchewan. However, as this study indicates, SaskEPS has some problems based on WiFi-signal and structural characteristics. Specifically, multipath poses critical risks which may increase SaskEPS's (and other WPSs) positioning error and reduces its reliability; however risks from the multipath effect can be reduced with using Maximum RSS for distance conversion. Furthermore, both 'Walkable CentreLINE Network' and 'Stay on the Meaningful Segment' functions helps reduce error associated with invalid locations by snapping raw positioning results to the closest CentreLINE segment. Some challenges still remain for SaskEPS to incorporate the map-matching method. For example, if the raw positioning result is located between two CentreLINEs, choosing which CentreLINE should be used for snapping is currently unspecified. This situation has the potential to be resolved by incorporating time-geography concepts that employ the last position of the user into the positioning process.

Although SaskEPS and other WPSs still need to overcome additional limitations before claiming ubiquity, our results suggest that a necessary element for navigation (CentreLINE) can also contribute to improve accuracy. To establish a true GPS-like positioning service (like car navigation), turn-by-turn navigation support is required for SaskEPS. Turn-by-turn indoor navigation will increase the usability of SaskEPS as a complementary positioning source for GPS.

In places such as airports, shopping malls, university campuses, terminals, and subway stations, SaskEPS would greatly increase convenience for both visitors and regular users of such places. SaskEPS has the potential to maximize the efficiency, convenience, and opportunity (ECO) for individual users, businesses, and industries that are integrated with indoor environments or isolated places (such as cruise ships and mining locales). Since smartphone use has increased, the demand for easy Internet connectivity has expanded; consequently, publicly available WiFi-network access is common and can be used for SaskEPS in many indoor environments. SaskEPS can be a solution to expand UPS and LBS into various indoor environments and to provide seamless positioning services from outdoors to indoors.

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CHAPTER 5

MODIFICATIONS IN HUMAN NAVIGATION PERFORMANCE AND PATTERNS BASED ON THE AVAILABILITY OF GPS-BASED NAVIGATION SYSTEM

5.1 INTRODUCTION

Novel technologies have brought many changes and advances to both our physical and social environments. Human spatial activity patterns have been altered by cumulative changes in the environment as well as technological and scientific innovations. While many of these innovations are associated with an improved quality of life, there are potentially unforeseen drawbacks. For example, while advances in transportation and related technologies have made navigation faster and easier, the spatial learning and related mental representations (our cognitive map) on which we have always relied might be compromised. Urban expansion in both vertical and horizontal dimensions also puts additional stress on navigation. In addition, with increased range (resulting from more efficient modes of travel) we are presented with new environments beyond our traditional home range.

Numerous communication tools for sharing geographic information have been developed. Conventionally, maps and verbal communication have played a major role in how we share spatial knowledge with others (Ishikawa et al., 2008). However, the quality and accuracy of acquired spatial knowledge is often inconsistent between individuals, and between places for the same individual (Golledge, 1999a). Since geographic knowledge relies on an individual's memory and ability to understand the environment, there is a risk of miscommunication when one shares spatial knowledge verbally. Alternatively, symbolized geographic information in map form is a fairly effective method for the delivery of geographic information. Maps can store a great deal of spatial and non-spatial information through systems of geodesy, symbology, generalization, and communication (Goodchild, 2007a). However, a map cannot contain all spatial observations and therefore represents a simplified and often specific view of the world that might not be suitable for all problems.

Humans successfully navigate with and without maps or related navigation aids; however, navigation tools are capable of providing much benefit to users as they support learning about novel environments remotely over short periods of time. Once an individual has a positive experience with such a navigation tool, the individual's trust in the tool may increase (Wei & Bell, 2012). With significant advances in Information Technologies (IT), navigation tools have become more accurate and reliable. Most of these tools are associated with and rely on the Global Positioning System (GPS). A GPS-based navigation system combines a network of Earth orbiting satellites with handheld receivers to provide ubiquitous positioning and navigation information to a user. As a result, there are demands for more efficient and seamless navigation tools as the use of location aware mobile devices grows (Bell et al., 2010). Fortunately, recent advances in location finding and mobile technologies help us access and leverage location information and detailed geographic information easily. Positive experiences with these advances can reduce spatial anxiety and risks while increasing navigation success. It also allows us to overcome various challenges faced during navigation related to changes in our expectations or simply finding ourselves lost (Waters & Winter, 2011). For these reasons, the use and popularity of GPS and Location Based Services (LBS) are increasing with the accompanying spread of smart devices (Jung et al., 2012).

The question remains, as it has from the first introduction of GPS, as to whether or not we truly need navigation tools beyond maps and verbal communication. If navigation tools such as GPS can help humans reach a destination efficiently and reduce spatial anxiety, what are the benefits and how can we maximize our navigation performance? What are the implications of using a form of assistance that might not be reliable? Are they drawbacks to using such technology? There is currently a lack of knowledge regarding how such navigation tools impact human navigation or how we process spatial knowledge. Many scholars have examined the positive and negative influences after use of technology-based navigation systems (Münzer, Zimmer, & Baus, 2012; Speake & Axon, 2012; Waters & Winter, 2011; Webber, Burnett, & Morley, 2012) but this research has focused more on long term impact, such as degradation of spatial knowledge or increased navigation efficiency with less spatial anxiety. There have been few studies examining the positive and negative influences during short-term use. This might include navigation behaviour changes based on navigation system availability during a single navigation task. For instance, what happens when a battery dies in a GPS unit that is being relied on for navigation support? One of benefits of using GPS is that even if we do not have enough spatial knowledge about the environment, the navigation system can provide seamless navigation strategies. If a user already has knowledge of the environment, such a system can support navigation by filling in gaps. Learning about such situations could help us employ navigation systems more wisely. The purpose of this study is to examine the difference in human spatial behaviour based on the availability of a navigation system during wayfinding. I examined the impact on human navigation with or without the navigation system as well as the impact of varying the levels of availability of such tools (not available, partially available, or full availability).

5.2 LITERATURE REVIEW

5.2.1 Challenges in Human Navigation

Navigation is a primitive yet indispensable spatial and cognitive ability. It is a foundational human capacity that is essential in meeting basic needs (Foo, Warren, Duchon, & Tarr, 2005). Many routine goals can be attained through proper navigation; successful navigation can make our lives more valuable and efficient. Navigation is goal directed spatial behaviour; once navigation has begun, it means the upcoming location (destination) is already determined, therefore during locomotion our remaining concern is how to get to the destination (Klippel et al., 2004; Montello, 2005). Therefore, investigating how navigation occurs, what we do when we are lost, and how efficient navigation happens are all important. When we travel through the same environment routinely and frequently, we incrementally acquire more knowledge and presumably become an expert (Hund & Nazarczuk, 2009). Navigation style and success can vary with the accuracy of the spatial knowledge held (Kalff & Strube, 2009) or type of environment (Bell, 2006; Ishikawa & Montello, 2006; Montello & Raubal, 2012). Researchers have been trying to fill this knowledge gap through study and experimentation, as well as through the development of navigation tools (Field, O'Brien, & Beale, 2011; Hirtle & Raubal, 2013; Huang, Schmidt, & Gartner, 2012; Ishikawa et al., 2008; Ishikawa et al., 2009).

Some have argued that modern navigation is more difficult due to urbanization and the increased complexity of built spaces; however, individuals are rarely completely lost in modern cities because various forms of spatial information are available for them (Lynch, 1960). In spite of having access to navigation tools, such as maps or verbal communication from others, navigation in unfamiliar environments (low spatial awareness), or with limited supplementary information (insufficient spatial information for the particular navigation task), might cause spatial anxiety or disorientation. As spatial confidence grows, our navigation strategies might narrow and our reliance on support (tools, maps, and directions) might diminish (Raubal, 2009; Stern & Leiser, 1988; Stern & Portugali, 1999).

The landscape of our community has been expanded in both physical and social dimensions (Antrop, 2004; Bell, 2006; Greider & Garkovich, 1994; Murdie, 1969; Stedman, 2003). Recent advances in Global Positioning System (GPS) and complex functionalities in many mobile devices have put a wealth of geographic and navigation information in our hands (Bell et al., 2010; Jung & Bell, 2013). These technological advances could reduce our spatial anxiety in unknown environments and prevent us from becoming lost. GPS-based navigation tools update dead-reckoning information for users. Furthermore, with integrated network data, Global Positioning System (GPS) can show the current location of a user with a small dot on the mobile display and deliver turn-by-turn navigation information based on integrated geographic information, including metric distance, time, heading direction, and speed along a selected route. Some advantages of using a GPS-based device include not needing to learn about the environment prior to travel and even if we do become disoriented or lost, the system can deliver an alternative route to reach our destination. These technologies represent the most recent in a long line of innovations that have altered the navigation and wayfinding process (Bell & Saucier, 2004).

5.2.2 Spatial Information Processing

Navigation can be described as purposeful locomotion to reach a destination though space (Montello, 2005). Wayfinding is the motivated and goal-directed process of selecting a path to a destination through locomotion (Golledge, 1999a). Many individuals' daily navigation is associated with both a spatial (Destination) and temporal goal (Arrival time). During navigation, an individual's path is generally associated with a particular navigation strategy that includes approximate travel duration and specific routes for their needs. Successful navigation requires the production of a route based on the knowledge held by the individual in their cognitive map. Since humans have begun to use alternative locomotion methods (horse, bicycle, vehicle, and others), the range of daily travel has increased. Such increases in range mean that larger amounts of spatial information must be processed in order to navigate successfully. As a result, we are continuously learning about the environment and acquiring spatial knowledge, which is not only useful for a particular environment but can be applied generally to the process of developing navigation strategies (Golledge, 1999b). For example, dense urban areas usually show high spatial similarity composed of a rectangular road network of blocks or sections with a consistent form of signage to support human navigation (Allen & Golledge, 2007; Golledge, 1999b). Consequently, for developing a navigation strategy, it should be associated with sufficient spatial knowledge to support spatial decision making for effective navigation. It should be noted that an individual's spatial knowledge can be acquired very differently depending on the legibility of the environment (Table 5.1) (Ishikawa et al., 2008).

Table 5.1 Environmental legibility

Environmental Legibility	Distinguishable Characteristic	Details
Complexity	Spatial Configuration	The spatial patterns of the objects in the environment
Differentiation	Distinctive Spatial Representative	Different environmental aspects such as scale, color, and shape significantly influence the physical environment
Visibility	Visual Difference	Observed spatial features linked with other spatial information

Furthermore, the quality of accumulated spatial knowledge is not only heavily influenced by environmental legibility / configuration (Hund & Nazarczuk, 2009; Lynch, 1960) but also individual experience (Blades, Lippa, Golledge, Jacobson, & Kitchin, 2002; Cornell et al., 2003;

Kalff & Strube, 2009), individuals' navigation efficiency could vary even if they have parallel navigation experience.

Spatial knowledge helps people understand their surroundings and to solve spatial problems for successful wayfinding (Kitchin & Jacobson, 1997). However, if our spatial knowledge is not complete enough for successful navigation, our navigation would be based on fragmented and partial spatial knowledge, so navigation errors would result (Klatzky, Beall, Loomis, Golledge, & Philbeck, 1999; Loomis, Klatzky, Golledge, & Philbeck, 1999). The necessary behaviours for acquiring spatial knowledge varies based on the shape and spatial extent of the environment (Bell, 2002; Montello & Freundschuh, 2005; Timpf, 1999). Spatial dissimilarity exists among different social and physical landscapes that can be distinguished based on the physical extent and configuration of a given environment (urban/rural or metropolitan/regional city). Metropolitan, urban, suburban, and rural spaces may require specific strategies to acquire spatial knowledge due to variability in the configurations and composition of physical features.

In known environments, where we have relatively complete spatial knowledge, getting lost is rarely a problem; however, if we need to travel to unfamiliar/unknown environments, getting lost or disoriented becomes a significant concern because we might have incomplete knowledge about the environment. Given enough time in a new environment, it becomes familiar and easily navigable, but it is almost impossible to experience and understand all environments or all of a single environment in a single experiential instance. The collection of spatial knowledge is a time consuming process, therefore humans cannot investigate or experience all environments before travel (Golledge, 1999b). In our contemporary society navigation tools can fill the knowledge gap where we do not have sufficient spatial knowledge for effective navigation; it can also help us correct or update our orientation during navigation (Raubal, 2009; Takemiya & Ishikawa, 2013; Yu-Ren, Chun-Yi, Yao-Chung, Horng-Chang, & Ming-Chiao, 2012). Recently, Ubiquitous Positioning System (UPS) and LBS can further support our spatial decision making and can make navigation more effective and easy in new environments (Burns, 1998; Raubal, Miller, & Bridwell, 2004; Winter & Wu, 2008). Because both UPS and LBS can deliver the required spatial information, including the incorporation of an individual's dead-reckoning and orientation information in real time, it is of unique value. In other words, navigation tools help to save time by delivering the necessary geographic information upon which one can establish spatial knowledge before visiting a certain environment and can help users overcome situations in which they feel unsure or lack adequate knowledge.

5.2.3 Benefits of Using Navigation Assistant Tools

Normally, navigation tools can assist wayfinding in both known and unknown environments and deliver the necessary spatial information to support effective navigation (Allen, 1999; Montello & Raubal, 2012). Static navigation tools, such as maps, offer support for ongoing navigation but might not be as useful as a dynamic system. The major concern regarding static navigation tools is that if we fail to perceive correct or complete spatial information, or fail to update our current location, it may cause stress and as a result affect cognitive systems related to successful navigation (attention, processing, etc.). For example, if we indirectly obtain knowledge about a novel environment and it does not match the actual physical environment, it will cause high spatial anxiety and reduce confidence. The wayfinding approach utilized by an individual varies based on the type of navigation tools used, the delivery method of the spatial information, and across individuals. Maps have long been a key method for conveying spatial information. Maps are preferable to other tools (verbal directions, sketches, narratives, etc.) due to their perspective, coverage, and simplicity (Meilinger, 2005; Pazzaglia & De Beni, 2001). This research will examine the extent to which a dynamically updated system can provide similar or improved navigation support.

When we use a map for navigation, we should continuously update (initiate) our current location on the map and maintain correct orientation, or at least (and likely) update it cognitively. If we fail to correctly orient ourselves with respect to the map and our location, we may lose our way or fail to reach our target destination. Furthermore, if we navigate an environment with fewer unique visual references (i.e. landmarks), we might have difficulty coordinating what we see with what we hold in our cognitive map (what we know). This risk can be reduced or absolved by UPS such as GPS-based navigation systems, which can inform both our relative and absolute location on a displayed map (Burns, 1998). These types of navigation tools may support successful and efficient navigation, even if individuals feel unsure about their orientation. Furthermore, such tools are also capable of selecting favorable/desirable routes based on travel time (fastest), travel distance (shortest), or other travel options (scenic or fewest turns) (Richter, Dara-Abrams, & Raubal, 2010) and provided navigation instructions can indicate any required actions such as turns (Krüger et al., 2004). Once users become experts with a navigation system, they can apply the system more advantageously toward their spatial activities (Dingus et al., 1997; Lee & Cheng, 2008).

5.2.4 Usefulness of Advanced Navigation Tools

Advances in both positioning and information technologies have provided plentiful additional choices for human wayfinding behaviour and strategies (Borriello, Chalmers, LaMarca, & Nixon, 2005). These technologies allow us to obtain rich geographic information quickly and effortlessly. The use of GPS is steadily growing, especially LBS (location based services), and we are being exposed to these technologies more frequently and for longer periods of time. In unfamiliar environments, these innovative navigation tools help us to reach our destinations efficiently and with reduced anxiety. When our cognitive map is incomplete, navigation tools can back up our spatial knowledge for less well known spaces (Raubal, 2009; Schmidt, Beigl, & Gellersen, 1999). If we have a relatively complete cognitive map, we can use a navigation tool as a supplement to our cognitive map. Additionally, supplemental navigation information could increase one's navigation confidence.

Mobile devices, particularly smartphones, have become increasingly popular, and as a result we are increasingly exposed to LBS. It is likely that many people stray from their normal, or preferred, navigation and wayfinding strategies as a result of mobile devices. Such devices can determine a user's absolute location and can track the device's movement, continuously tracing its spatial and temporal position on the screen (Retscher, 2006). If we use these navigation services, we may be able to enter a new environment stress-free and without prior experience or learning. But, if we rely on a navigation system for wayfinding, it is important to understand how the availability, or the presence, of such a device during navigation can impact and modify our navigation behaviours. Many researchers have studied human spatial activities through currently available positioning systems (Field et al., 2011; Ishikawa et al., 2008; Speake & Axon, 2012). Unfortunately, there is a lack of information about the ways such navigation tools impact our ability to navigate and process spatial knowledge in the same environment. At the same time, there are demands for more efficient and reliable navigation tools as the use of location aware mobile devices grows (i.e. cellphones, smartphones, laptops, and other mobile devices).

5.3 QUESTIONS REGARDING THE USE OF ADVANCED NAVIGATION TOOLS

As outlined above, navigation tools have increased the efficiency of our navigation and wayfinding. However, there is a lack of information about the ways such navigation tools impact our ability to navigate and process spatial knowledge. Ishikawa (2008) indicated that technology-based navigation tools affect human wayfinding behaviour, where humans acquire spatial knowledge differently in active versus passive settings (Conniff et al., 2010; Feldman & Acredolo, 1979). GPS-based navigation systems generally provide accurate location information, but on their own do not deliver the associated spatial information that is tailored to the individual user and their task. For example, a driver may receive a route description, which is determined by the navigation system without a driver's critical reasoning. As a result the driver does not have the opportunity to play a role in the planning of his or her route. The driver may or may not be concerned with what kind of spatial information is available and what criteria are used for route selection. The presence of the navigation system necessarily alters the driver's participation in route selection; it moves their navigation from an active towards a passive activity. If we rely on navigation systems for wayfinding, it is important to understand how the availability of such a system can impact and modify our navigation patterns and behaviours. Availability refers to the presence of a GPS device during navigation.

The purpose of this study is to examine the differences in human spatial behaviour based on the availability of a navigation system during wayfinding. GPS-based navigation tools may result in a transition of navigation from active (that which is done with a full attention to one's whereabouts) to passive (that which is done with reduced critical reasoning). It is also beneficial to evaluate the usefulness of the GPS-based navigation system for use in complex urban settings (i.e. determination of a correct route and reducing disorientation problems). This research also examines how humans react to and acquire geographic knowledge when navigational tools are both available and unavailable (or unreliable). Furthermore, this research may contribute to the improved efficiency of navigation systems.

5.4 METHOD

The primary concern of this experiment was to investigate the consequences of two navigational situations: consistent navigational status or a change in the navigational status (gain or loss of access to the GPS device) during navigation. The research was conducted in three steps. In the first step, a pre-navigation questionnaire and three spatial psychometric tests took place in a quiet room with participants receiving directions via iPad (SaskEXP application). In the second step, changes in human navigation were observed based on the availability of a GPS-device in outdoor environments. Four navigation groups (conditions) were used to test the impact of navigating with or without GPS as well as the impact of varying levels of availability of GPS (not available, partially available, or full availability). In the third step, the impact of the availability of GPS on human spatial cognition was examined via a survey and sketch map task.

5.4.1 Participants

Measuring the difference in human spatial behaviour based on the availability of navigation tools was conducted with 60 participants. Each participant was randomly assigned to one of four navigational groups (Table 5.2: all navigation occurred on the University of Saskatchewan (UofS) campus):

Table 5.2 Four navigation conditions of the experiment

Condition	Type	Detail
Full GPS Support	Active Navigation	No navigational support for the entire navigation experiment.
Gain GPS Support	Active to Passive Navigation	No navigational support in the first half of the navigation experiment with navigational support in the second half of the navigation experiment
Lose GPS Support	Passive to Active Navigation	Navigational support in the first half of the navigation experiment with no navigational support in the second half of the navigation experiment
No GPS Support	Passive Navigation	Full Navigational support for the entire navigation experiment

Each experimental group was balanced in terms of sex (Figure 5.1: 7 females & 8 males or vice versa).

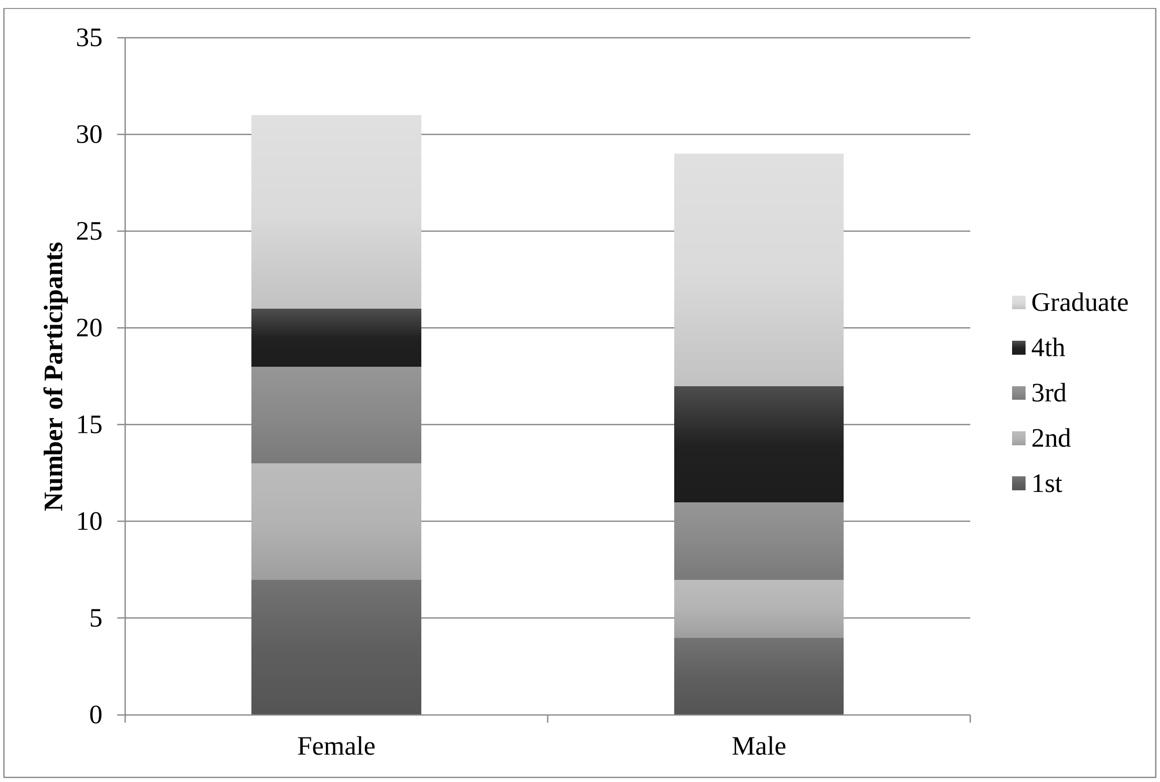


Figure 5.1 Distribution of participants' sex and year of study

Participants were randomly assigned to a navigational condition; no navigation condition information was given to the participants until they were located at an outdoor starting point. Furthermore, participants were unaware whether they were going to gain or lose the GPS-device following completion of the first path in the navigation task.

5.4.2 Experimental Routes

Two paths were developed for the experiment, as two of the four navigation conditions were characterized by switching the navigation condition from "Active" to "Passive" or vice versa (Figure 5.2).

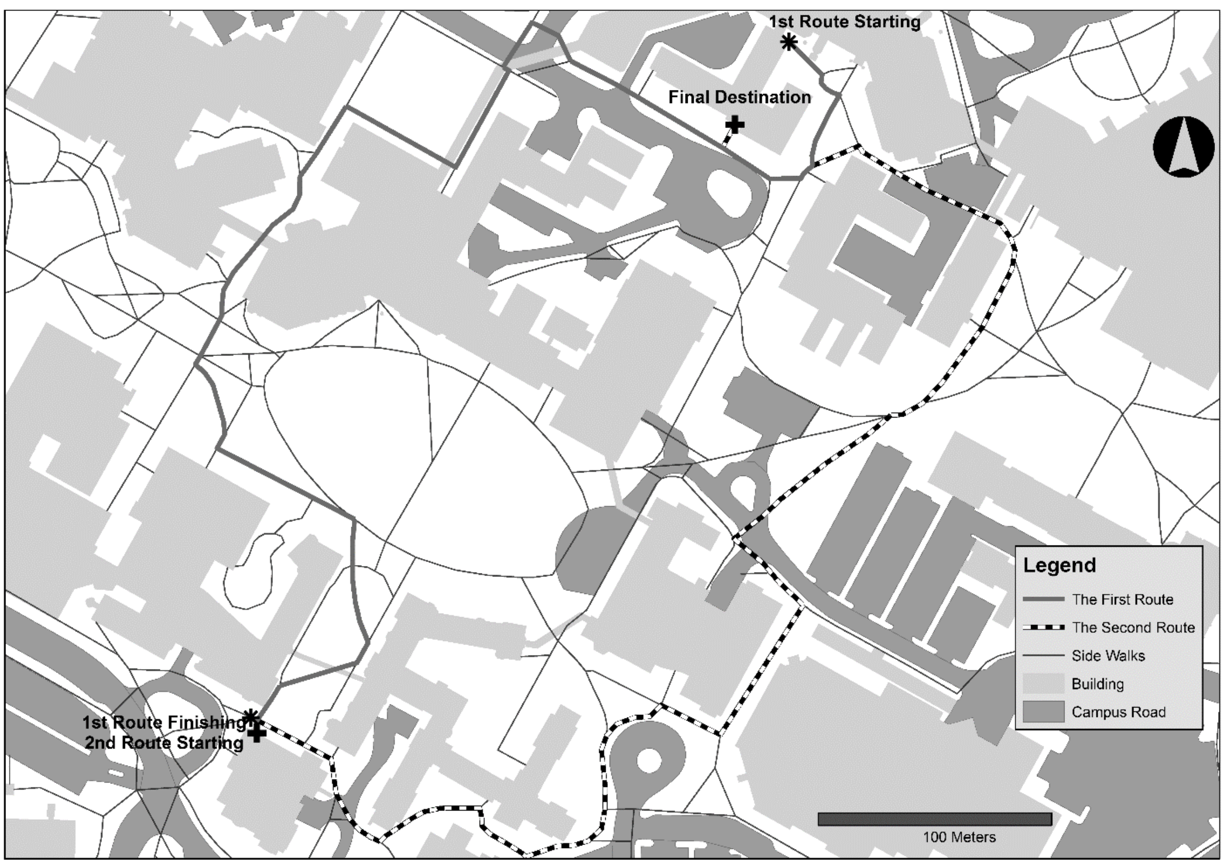


Figure 5.2 University of Saskatchewan campus maps and experimental route

The full route consisted of two paths: first a 700m path, then a second 740m path, each consisting of 10 turns. All trials began and ended at the same building. This experiment was performed between May and August of 2012. During this time pedestrian traffic was low to moderate. Furthermore, no experiments were performed during inclement weather, meaning participants are assumed to have navigated with a similar path, exposed to similar conditions.

5.4.3 Procedure

In the first part of the experiment, prior to performing the given navigation condition, a pre-navigation questionnaire and three spatial psychometric tests were given to each individual participant. The questionnaire was designed to evaluate each participant's familiarity with the UofS campus and navigation systems. The Santa Barbara Sense of Direction Scale (SBSOD), Object Location Memory Test, and Mental Rotation task were also delivered. These tests were used for the evaluation of participants' spatial abilities based on standardized tests. In the second part, participants were asked to familiarize themselves with the pre-developed experimental routes using a paper map for 3 minutes (Figure 5.3).

This route familiarization process was intended as an opportunity to learn the experimental route, develop a wayfinding strategy, and deliver a baseline level of spatial knowledge to all individual participants prior to beginning their journey. When participants did not have GPS-support, participants needed to depend on what they learned and recalled from the route familiarization process. Furthermore, participants were asked to follow the mapped route as closely as possible. Upon completion of route familiarization, an experimenter accompanied participants to the starting point.

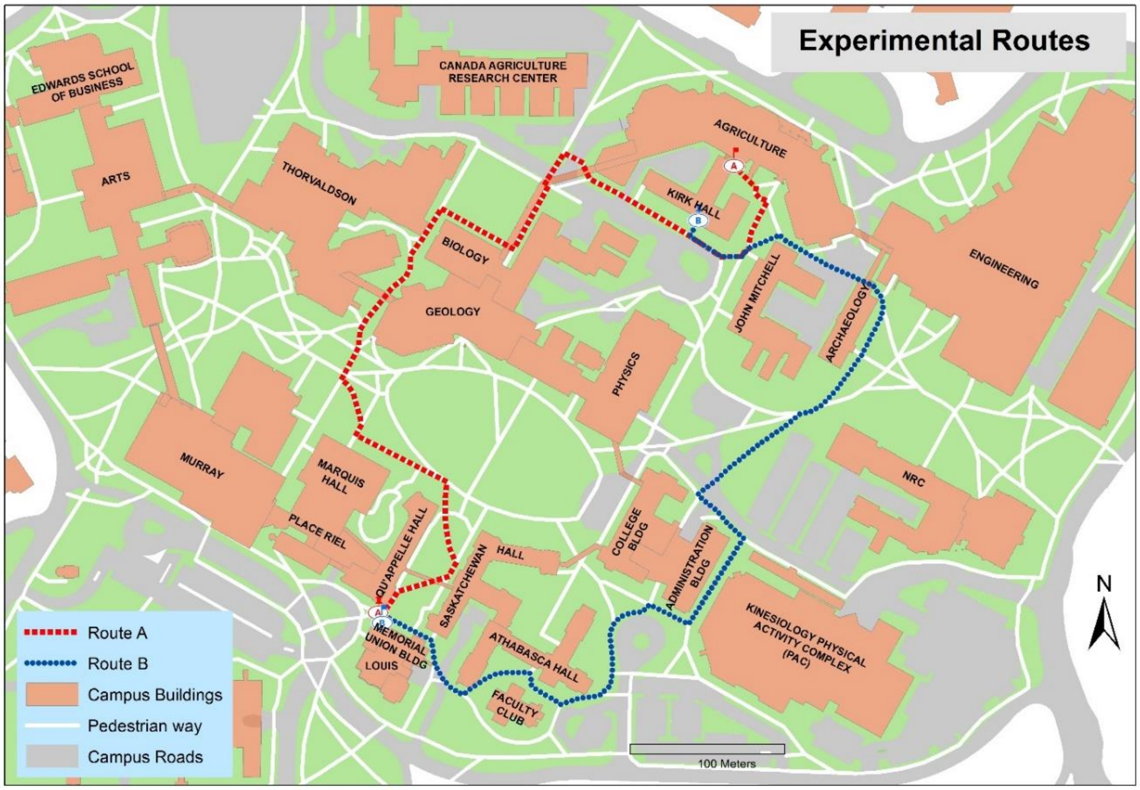


Figure 5.3 A map provided to participants during the experiment (11 inch by 17 inch)

Prior to beginning the navigational task, participants were given a GPS-handheld device (TrimbleTM Juno SC GPS handheld), which was designed for recording navigation patterns. In addition, participants in passive conditions were given another GPS-handheld device displaying the experimental route with a map similar to what they had used during route familiarization (Figure 5.4). The second GPS device delivered participants' current location and heading on the map. For better positioning results, all GPS-based positioning devices were warmed up and checked for positioning accuracy before the start of the experiment. Both GPS devices functioned consistently throughout all trials of the experiment. Pointing tasks were given to the participants following completion of their navigational tasks. During the participants' outdoor activity, an experimenter followed them for safety purposes and to observe their spatial behaviour.

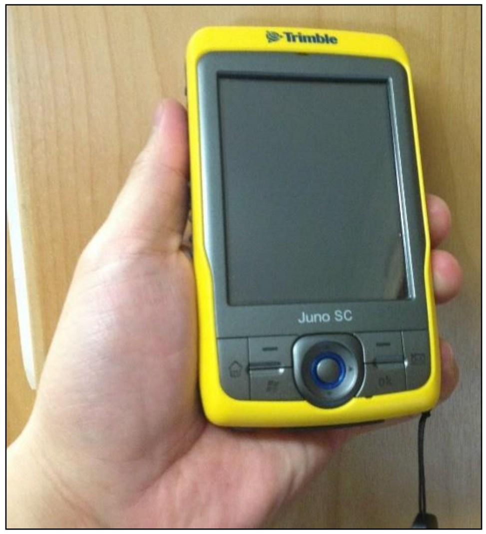


Figure 5.4 Trimble™ Juno SC GPS handheld

Detailed observations were also recorded on an experimental observation sheet (Figure 5.5), which was designed for tracing each participant's movement (backup / evaluation for GPS-tracing record) and tracking spatial behaviour. In the final part of the experiment, participants were asked to draw their travelled path on a paper map illustrating certain campus buildings. As well, participants were asked to complete a post-navigation questionnaire, in order to elucidate their navigation experience with or without a GPS device during the experiment.

GPS devices loaded with a campus map were used to provide spatial information about the experimental routes. Most students had little to no difficulty in understanding the map on the display of the GPS device. GPS accuracy and reliability were evaluated several times along the experimental routes prior to beginning the experiment and for the most part, provided accurate positioning results. Furthermore, to insure GPS accuracy, all GPS almanac data were reviewed and real-time Positional Dilution of Precision (PDOP) was also recorded; no significant concerns arose. No severe positioning interruption was reported by participants for the duration of the experiment or presented in the participants' GPS-traced results. When participants finished their navigation task, they were moved from the second path's end to a nearby open location for pointing. They were asked to point to 15 specific locations along the experimental route with a mobile pointing task application (SaskEXP) on an iPad (Berry & Bell, 2014). Participants also went back to a quiet place for finishing a post-survey and a sketch map task.

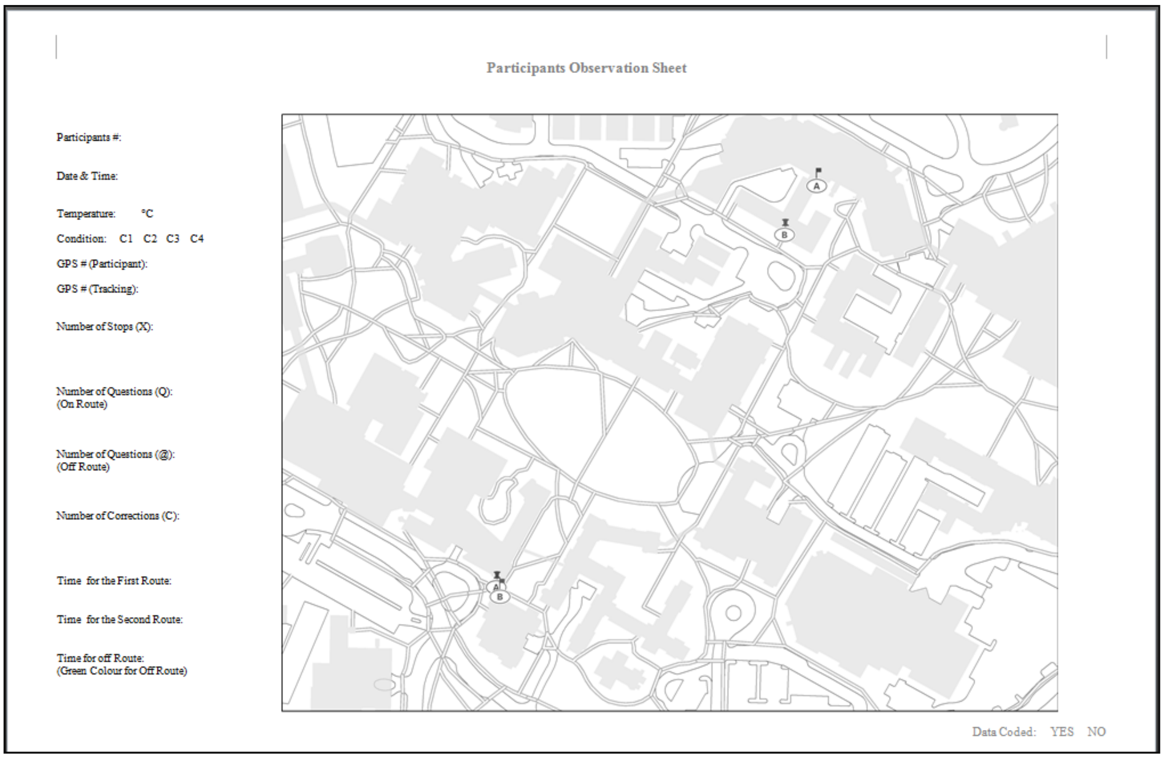


Figure 5.5 Experimenter's observation note (11 inch by 17 inch)

5.5 RESULTS

All navigation and path following results are based on the tracking form that was manually recorded by the researcher. GPS tracking data will be separately analyzed in section 5.6.5.1.

5.5.1 Pre-Survey and Psychometric Tests

Participants' spatial abilities and other possible influences needed to be evaluated prior to analysis of navigation performance (Table 5.3).

Table 5.3 Participants' basic information and spatial tests results

Path	**GPS Availability**	**AGE** Mean (Std)	**Spend time in UofS** Mean (Std)	**SBSOD** Mean (Std)	**Mental Rotation Correct Answer** Mean (Std)
First	Active	26.0 (5.8)	3.4 (1.5)	4.0 (0.4)	39.0 (0.4)
	Passive	27.3 (7.6)	3.3 (1.6)	4.1 (0.4)	39.7 (8.2)
Second	Active to Active	29.0 (8.6)	2.9 (1.7)	4.0 (0.5)	37.5 (9.4)
	Active to Passive	25.5 (5.3)	3.8 (1.3)	4.2 (0.4)	41.9 (5.7)
	Passive to Active	25.1 (3.9)	3.5 (1.3)	3.9 (0.4)	40.6 (6.4)
	Passive to Passive	26.9 (7.2)	3.3 (1.2)	4.0 (0.4)	37.4 (8.0)

Most participants were of a similar age and *sense of direction* (SBSOD), however some differences were found in the period of time spent on the UofS campus. In addition, almost half of all participants owned smartphones and had prior experience with GPS devices. Only two possible navigational conditions were available for the first path: either with GPS, or without. In terms of the campus familiarity, most participants indicated they had fair knowledge of the UofS campus, but they indicated less confidence in their spatial knowledge near the engineering building, a somewhat peripheral location on campus and associated with portions of the second path (Figure 5.6).

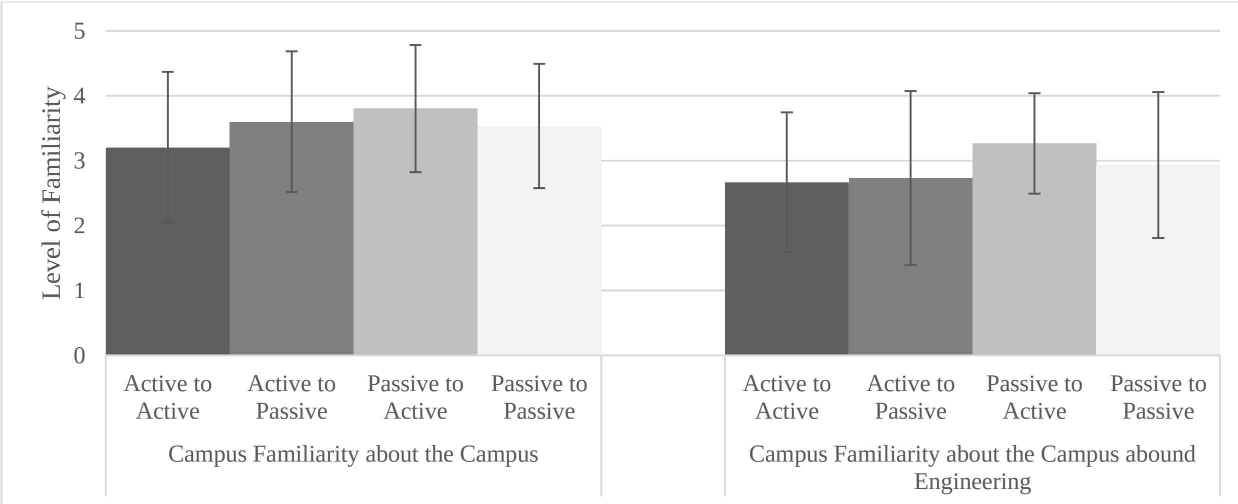


Figure 5.6 Campus familiarity difference between each navigation condition

5.5.2 Results of Navigation Performance in the First Path

As mentioned, four different navigation groups were used for the experiment, and could be summarized into two navigational conditions for the first path; therefore, navigational conditions 1 and 2 can be categorized as active navigation conditions (ACTIVE), while navigational conditions 3 and 4 can be categorized as passive navigation conditions (PASSIVE) (Table 5.4).

Table 5.4 The availability of the GPS-based navigation system by navigation condition

Navigational Conditions	First Path		Second Path		
	GPS availability	Mode	Status Change	GPS availability	Mode
1 (A-A)	No	Active	Same	No	Active
2 (A-P)	No	Active	Gain GPS	Yes	Passive
3 (P-A)	Yes	Passive	Lose GPS	No	Active
4 (P-P)	Yes	Passive	Same	Yes	Passive

Participants of ACTIVE began navigation of the first path without GPS, and participants of PASSIVE began with GPS. Four different navigational conditions were available for the second path: continue without GPS (A-A), gain GPS (A-P), lose GPS (P-A), or continue with GPS (P-P). Many participants in all groups took off-route paths in the first path (Table 5.5).

Table 5.5 Comparison of travelled distance and off-route distance based on navigation conditions (First path only)

	First Path	
	Active	**Passive**
Travelled Distance (Mean in Meter)	689.72	732.86
Exceeded Travel Distance (%)	-1	5
Off-Route Taker (%)	100	73
Overall off-route frequency per participant (Mean)	2.73	1.43
Proportion of shortcuts (%)	77	53
Rate of increased travel distance (%)	23	23

Significantly difference results for both travelled distance and off-route length among different conditions (ANOVA: all p-value<0.01)

Overall the distance traveled by participants in the ACTIVE condition was associated with greater *off-route distance* than PASSIVE. Use of off-route paths appeared much greater for ACTIVE; however, the number of participants who travelled off-route was high for both navigational conditions in the first path (over 70%). All participants may have encountered challenges in becoming familiar with the route and the GPS. Interestingly, while all ACTIVE participants traveled off-route, their mean total travel distance was shorter than the actual experimental route distance. This indicates that participants utilized shortcuts rather than the longer, pre-determined route (Bell & Goodall, 2004) (Figure 5.7).

On the other hand, PASSIVE participants' mean travel distance was 5% longer than the actual length of the first path; however this can be attributed to correction behaviours after heading in the wrong direction (Figure 5.8). PASSIVE participants often attempted to correct their direction upon the realization that their current location and GPS location were mismatched. This problem might be caused by the novelty of the navigation system and the ability to see where they were at all times.

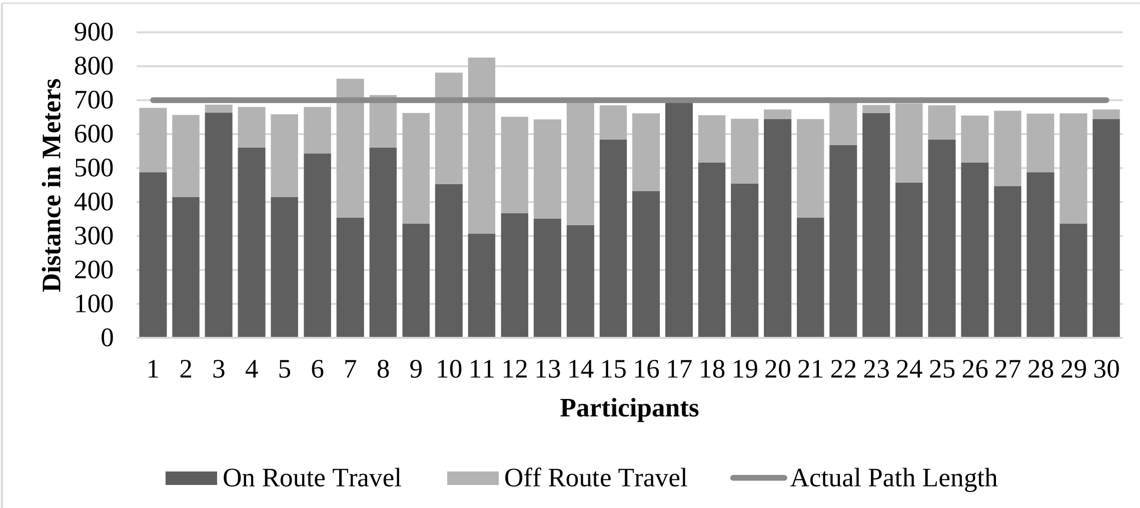


Figure 5.7 ACTIVE: travelled distance in the first path and On- & Off- route distance

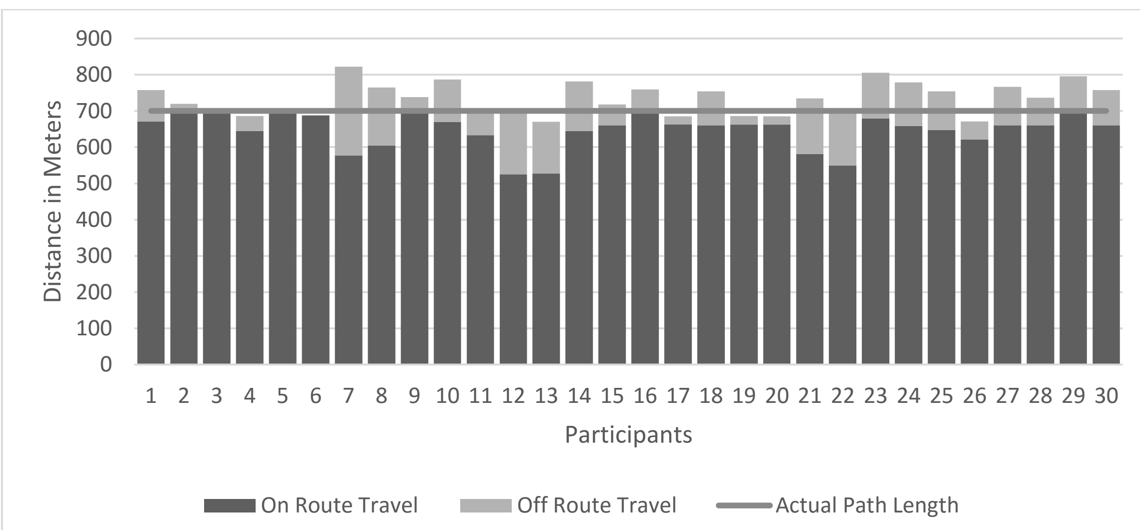


Figure 5.8 PASSIVE: travelled distance in the first path and On- & Off- route distance

Both ACTIVE and PASSIVE participants should have had relatively good recall of the first path which they studied. ACTIVE participants improved (shortened) their travel with shortcut based on their own spatial knowledge (Figure 5.9). At the same time, PASSIVE participants paid greater attention to the navigation system; therefore, there is little surprise that PASSIVE participants' travel distances are further than ACTIVE participants' travel distance (as though the system were saying, "stay on the path, it will lead you to your destination") (Figure 5.10).

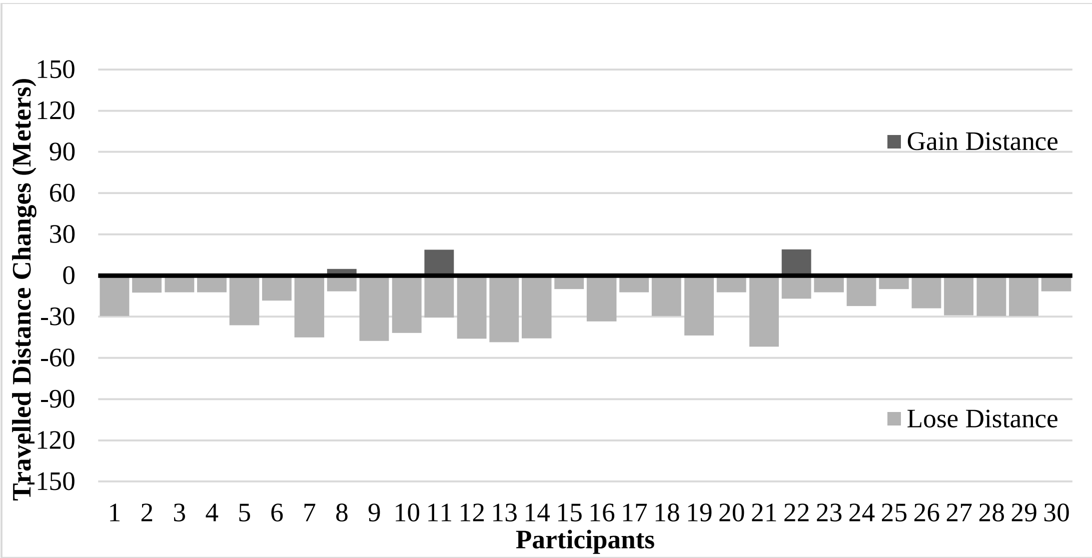


Figure 5.9 ACTIVE: Off-route characteristics by gain or lose distance

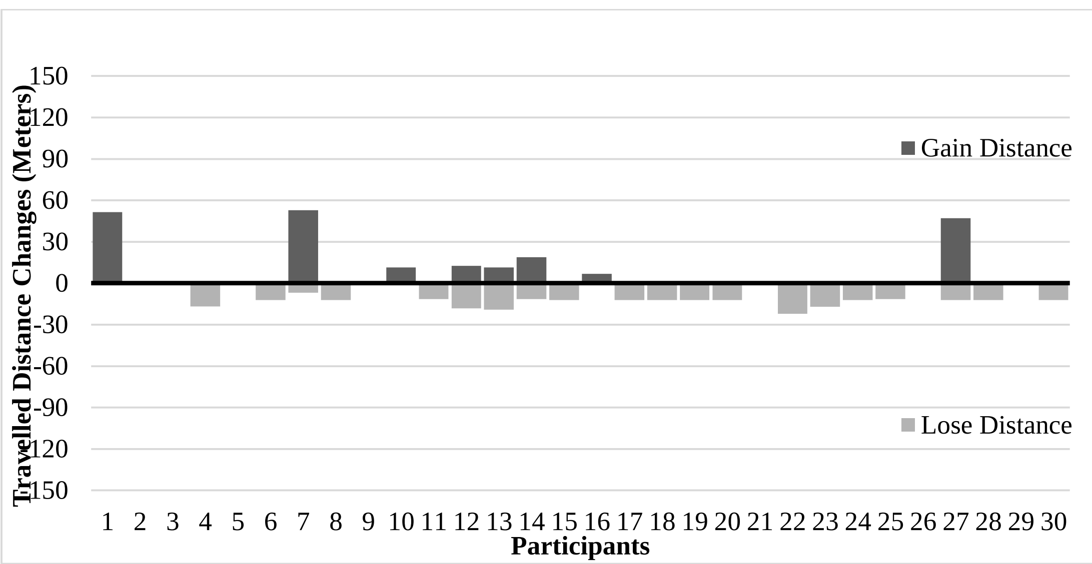
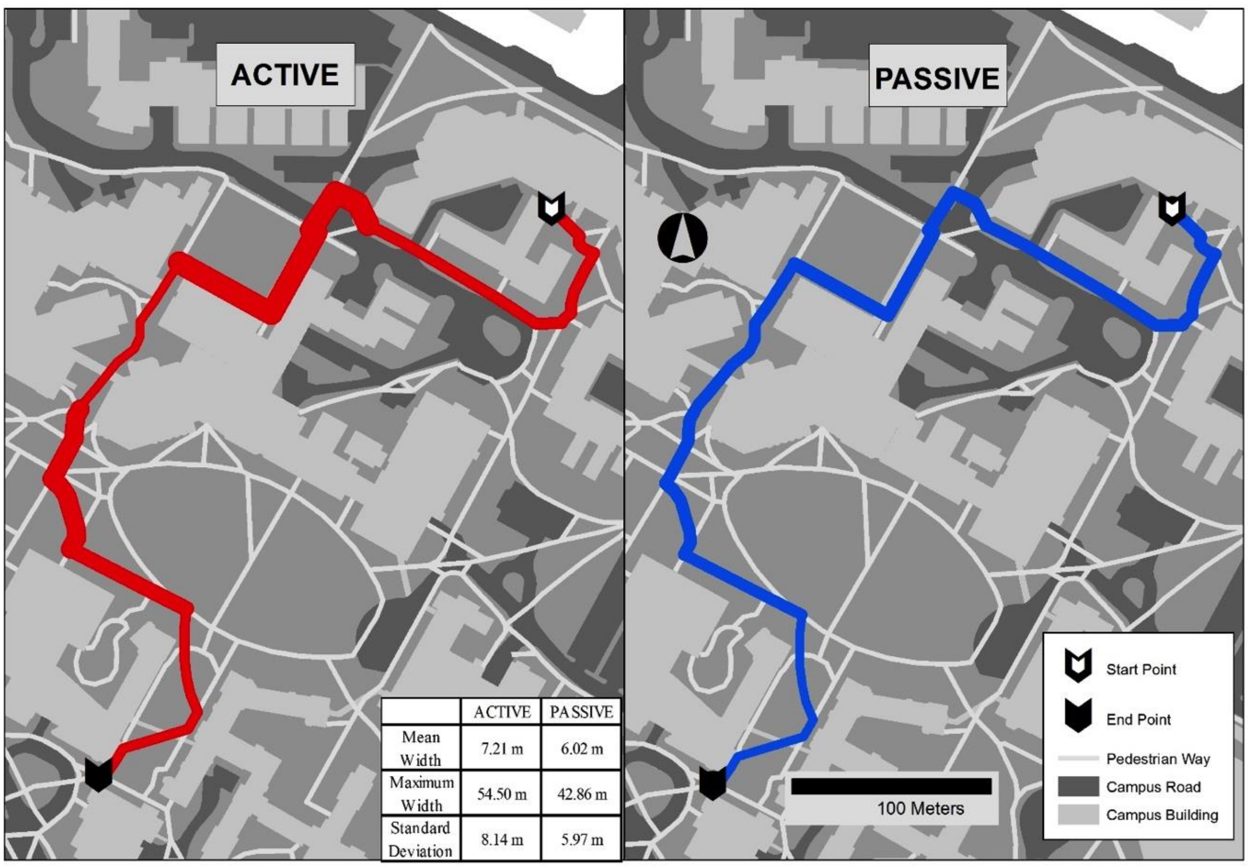


Figure 5.10 PASSIVE: Off-route characteristics by gain or lose distance

In figure 5.11, participants' paths were aggregated into a single tube that represented the *mean path width* of how far participants' travel away from the correct path. A wider line symbol indicates greater variation in off route travel in that area. For the first path, both ACTIVE and PASSIVE participants took numerous off-route paths, so their tube width is quite similar, but ACTIVE participants show more hesitation in certain portions of the path where their route selection becomes more inconsistent (with greater standard deviation value) than other parts of paths (Figure 5.11).



	ACTIVE	PASSIVE
Mean Width	7.21 m	6.02 m
Maximum Width	54.50 m	42.86 m
Standard Deviation	8.14 m	5.97 m

Figure 5.11 Mean width of taken path in the first path (wide tube width (less consistency) to narrow tube width (high consistency))

When comparing ACTIVE and PASSIVE participants on the first path, PASSIVE participants stopped more frequently than ACTIVE participants. PASSIVE participants might not have been familiar with the navigation system, so perhaps they took time to match their location with given location of GPS (Figure 5.12).

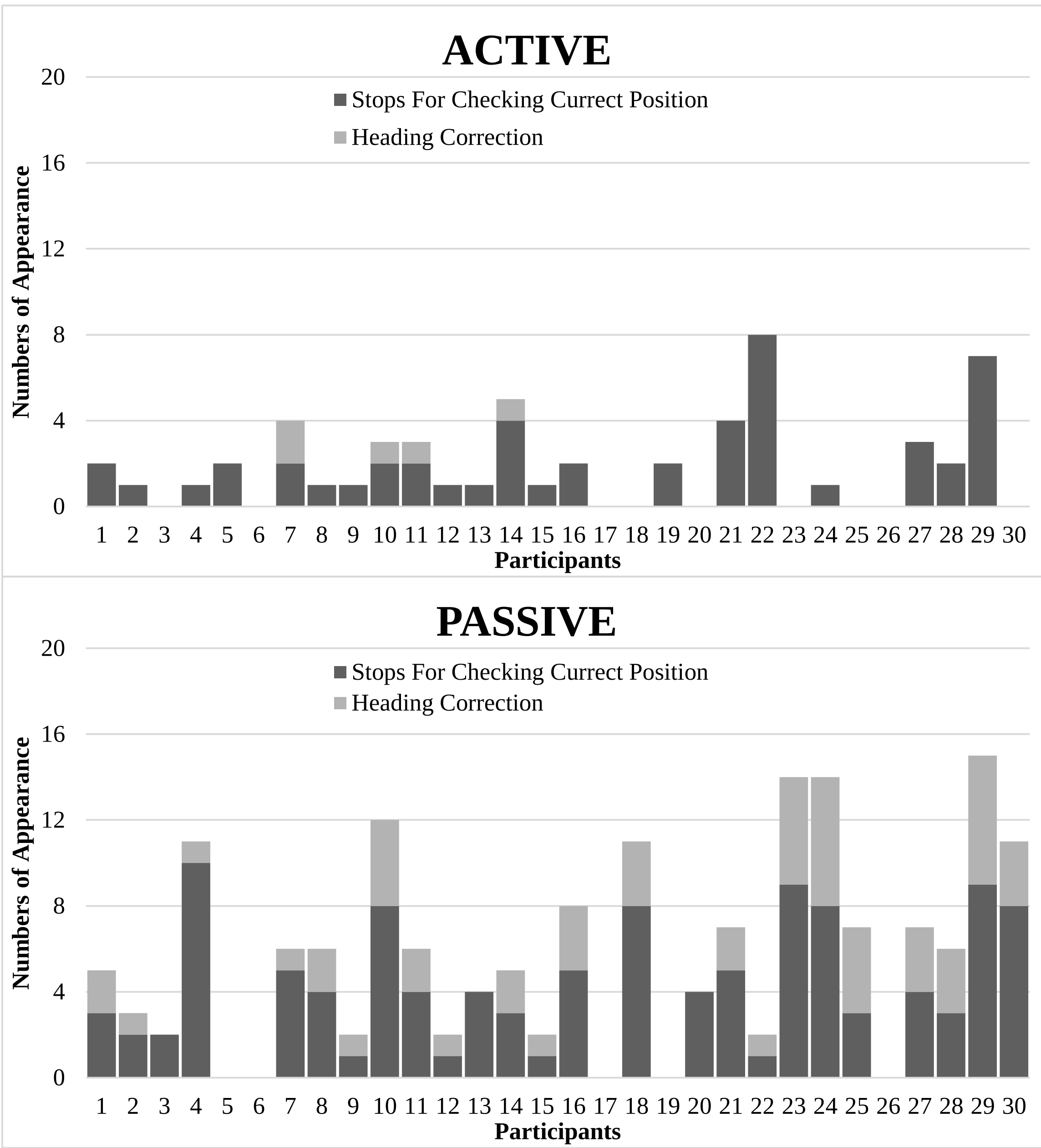


Figure 5.12 Number of stops and self-heading correction attempts in the first path

Furthermore, PASSIVE participants more frequently attempted to correct their direction, mostly after checking their position in the GPS so their *stopping* points are also self-correcting spots (Figure 5.13).

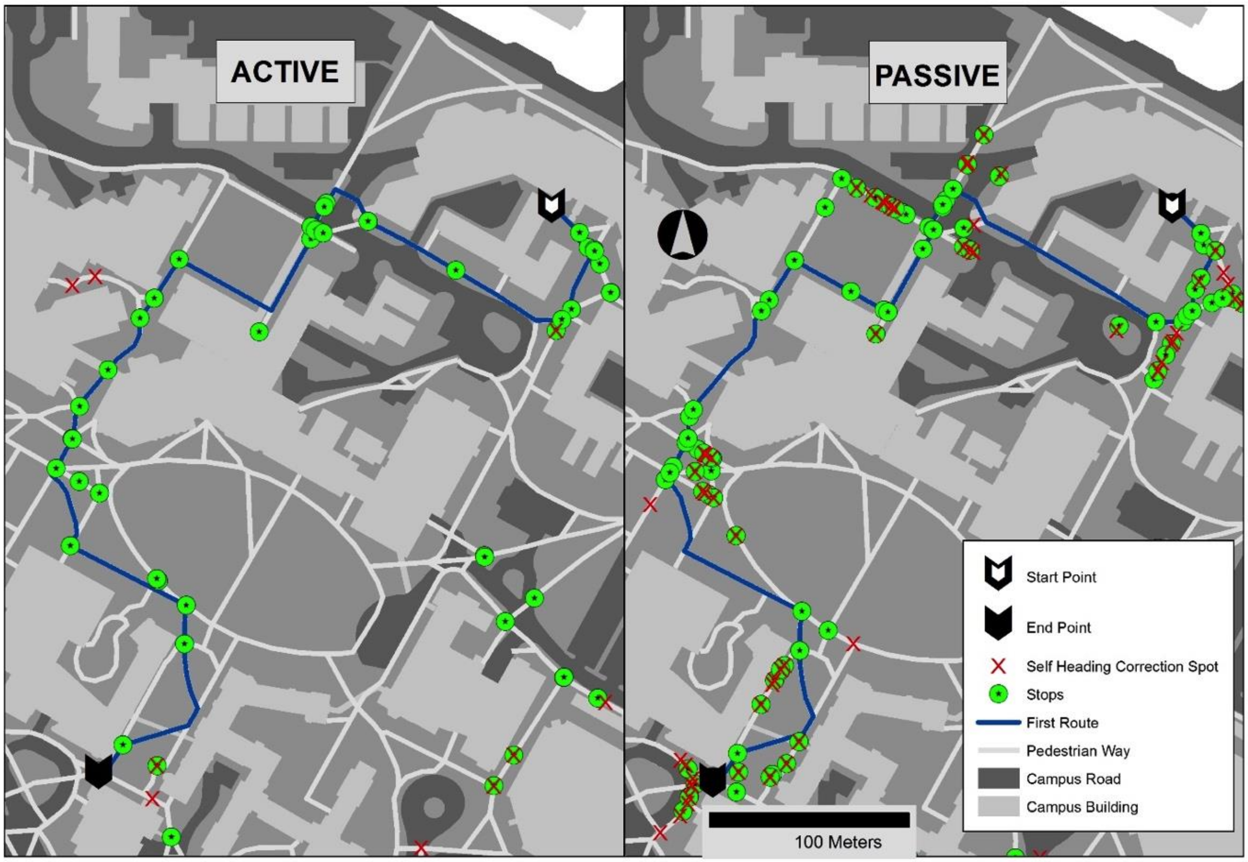


Figure 5.13 Stops and where participants corrected their heading in the first path

Many *self-heading corrections* were made in the area where a bottleneck (path connectivity decreased: many to one) began or where path choices were suddenly increased (path connectivity increased: one to many). PASSIVE participants followed GPS-given directions, causing them to be greatly dependent on the spatial information given there, without making their own spatial decisions or applying critical reasoning towards their orientation. When their current GPS location was off of the experiment route, they immediately attempted to correct their direction. ACTIVE participants were unaware of whether they were out of the experiment boundaries or not. Most incorrect heading attempts continuously force them to travel in the off-route accidentally.

In the first path, ACTIVE participants showed better navigation performance than PASSIVE participants because they could successfully link their existing spatial knowledge about UofS campus and a given navigation strategy with a map before the navigation task began. However, ACTIVE participants still exhibited off-route or very inefficient paths for reaching the destination.

5.5.3 Results of Navigation Performance in the Second Path

All participants in the active conditions traveled both on and off the second path, but the cost of using off-route is much different between the participants (ACTIVE) in the first path and the participants (A-A and P-A) in the second path (Table 5.6).

Table 5.6 Comparison of travelled distance and off-route distance based on navigation conditions

	First Path (700 m)		Second Path (740 m)			
	ACTIVE	PASSIVE	A-A	A-P	P-A	P-P
Travelled Distance (Mean)	689.72	732.86	827.35	769.06	882.37	777.04
Exceeded Distance (%)	-1	5	12	4	19	5
Off-Route Taker (%)	100%	73%	100%	53%	100%	33%
Overall off-route frequency per participant (Mean)	2.73	1.43	2.80	0.80	3.07	0.36
Proportion of shortcuts (%)	77	53	27	13	13	13
Rate of increased travel distance (%)	23	23	73	7	87	7

Although ACTIVE participants frequently traveled off-route in the first path, their off-route travel was highly associated with shortcutting, so their overall travel distance was shorter than the actual length of the first path. On the other hand, both A-A (active 1st path, active 2nd path) and P-A (passive 1st path, active 2nd path) participants' off-route travel was more inefficient, so their overall travel distance were quite longer than actual length of the second path (Figure 5.14). Specifically, for the first path, over 75% of off-route travel made by ACTIVE participants could be categorized as shortcut paths but the shortcut portion within total off-route travel dropped to 27% (A-A) and 13% (P-A) from path one to path two (Figure 5.15).

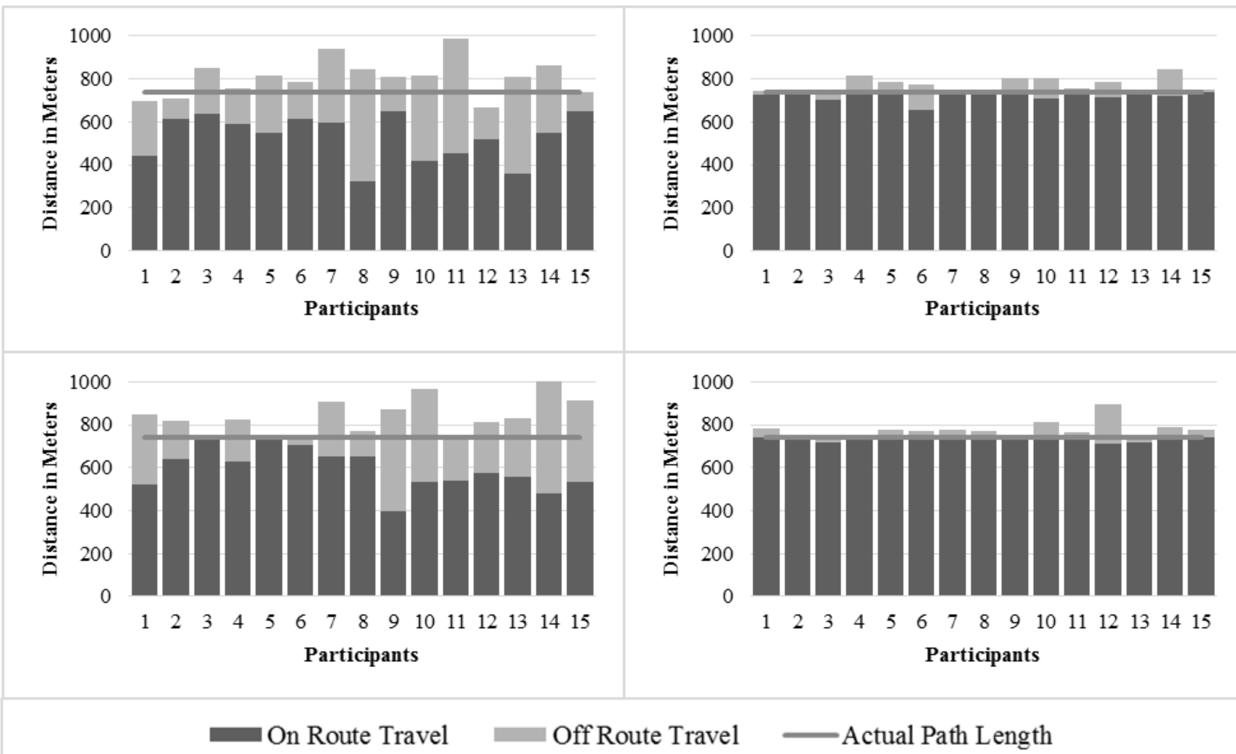


Figure 5.14 Travelled distance in the second path and On- & Off- Route distance by navigation conditions

This indicates that either the participants' route knowledge comparably decreased or the paths were different enough to discourage their travel on path two. Dissimilarly, for the second path, participants in the passive conditions (A-P and P-P) traveled off-route less frequently than

PASSIVE participants who had enjoyed the same navigation condition as path one. This indicates that either the participants became better GPS users (P-P), increased their familiarity of paths and surroundings based on active navigation experience (A-P), or the second path was different enough to encourage greater on route travel.

Not surprisingly, P-P participants tended to travel off-routes most infrequently among all groups/conditions. In addition, these individual's navigation effectiveness increased for the second path (33% of P-P participants travelled 53.3 meters (mean) off-route). This result, summarized in Table 5.6, might be affected by the level of familiarity with the GPS-based navigation system. For comparison, A-P participants' path 2 off-route travel frequency was much lower than the first path and this improvement is more noticeable than all other groups/conditions. It represented that appearance of the GPS-based navigation system could prevent participants from off-route travel. On the contrary, P-A participants' off-route travel frequency is considerably increased after they lost their GPS-based navigation system for the second path. It characterized that if a user is aware of their surroundings and can integrate GPS, the system becomes more useful and helpful even if a user has low familiarity on the system.

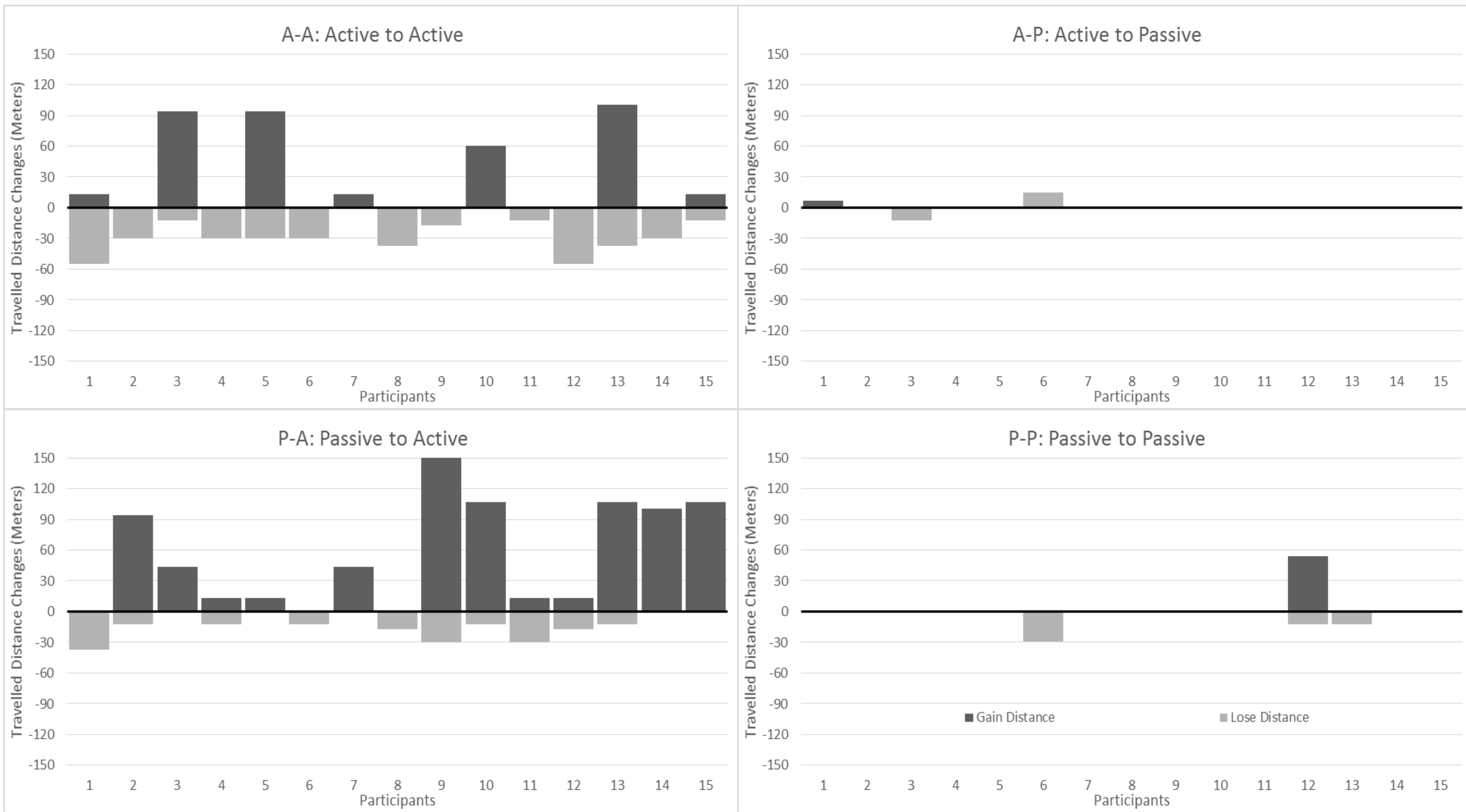


Figure 5.15 Off-route characteristics by distance change in the second path

In the first path, there is little mean path width difference between ACTIVE and PASSIVE. For the second path, mean path width for PASSIVE navigators is notably increased (Figure 5.16).

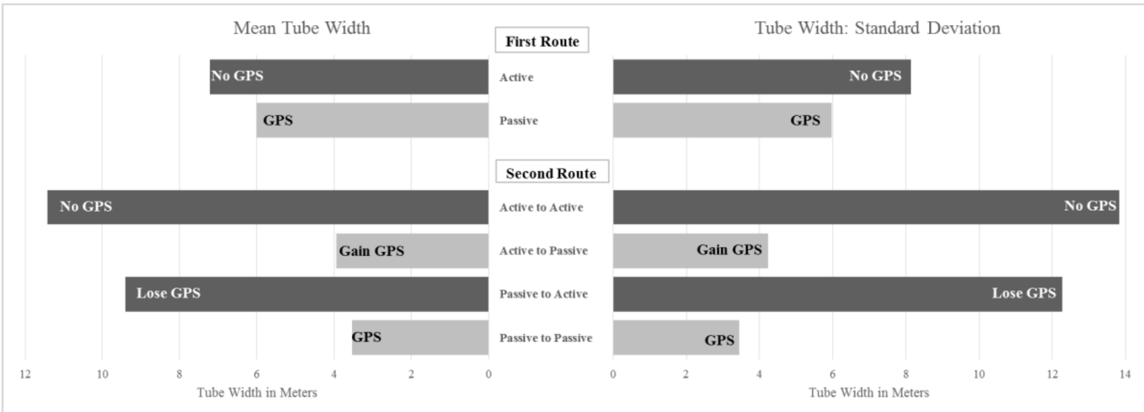


Figure 5.16 Taken path width comparison

When participants did not have GPS support in the second path, their path selection became more dissimilar and inconsistent, so their off-route distance was greater. If participants had GPS-support for the second path, their path width is narrow with little difference among the selected/taken paths. By contrast, participants who did not have GPS support for the second path had a harder time determining the correct heading from the path starting point, so their path width was substantial (Figure 5.17).

Furthermore, when participants did not have GPS, less than 20% of participants recognized they were off-route and corrected their heading to correct direction. In many cases they ended up taking an alternate path (off-route) or were corrected by the experimenter. However, when participants navigated with GPS, there were more frequent stops but they easily recognized they were off route. GPS information helped them update their heading. However, A-P participants were more likely to ignore the GPS on their second path, ignoring the GPS generally happened when their off-route travel was for short distances (minor effect on travel distance or time which could be observable in the GPS display). Having actively navigated the first path without GPS they were in an "active" mode of wayfinding; making selective, as opposed to continuous, use of the GPS a more routine part of their navigation strategy. This suggests that by first navigating actively they have primed their active "system" and are therefore inclined to preferentially use active techniques, even in the presence of a GPS. Figure 5.16, shows that A-P participants traveled off-route more than P-P participants.

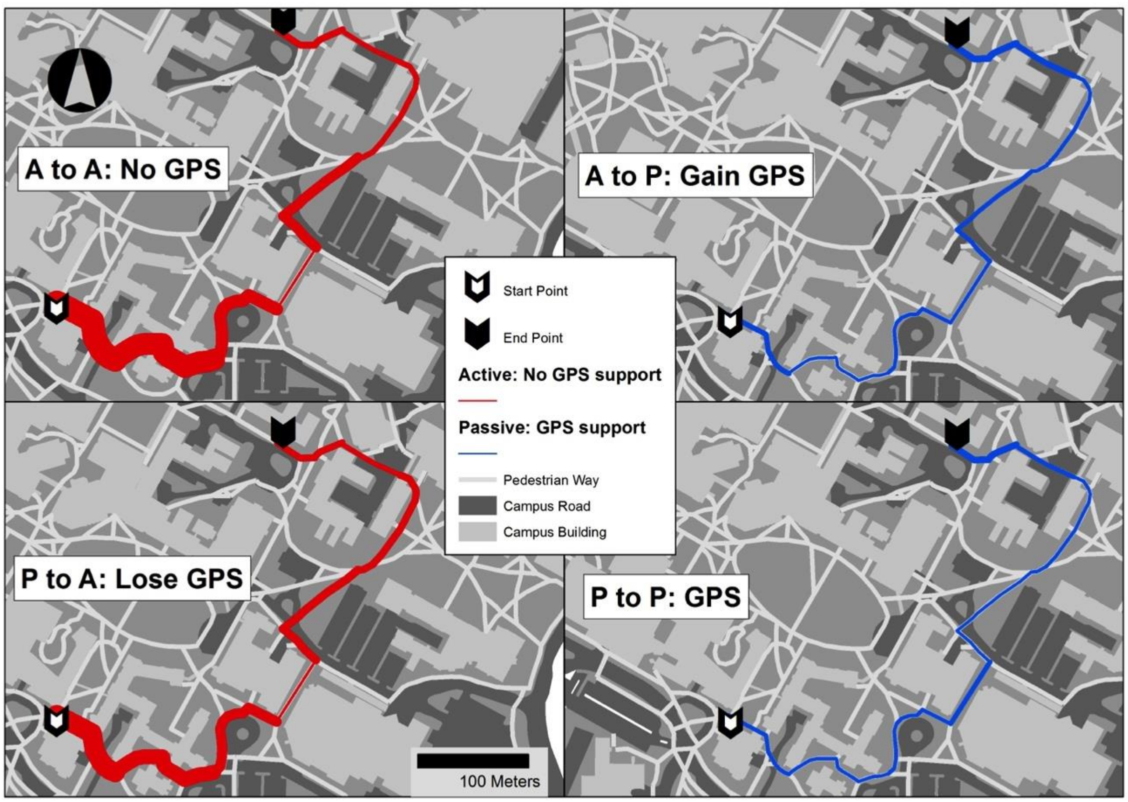


Figure 5.17 Mean width of taken path width in the second path

For *number of stops* and *self-heading correction* there was greater similarity between A-P and P-P participants (Figure 5.18). Most P-P participants made stops where they needed to decide which direction to travel.

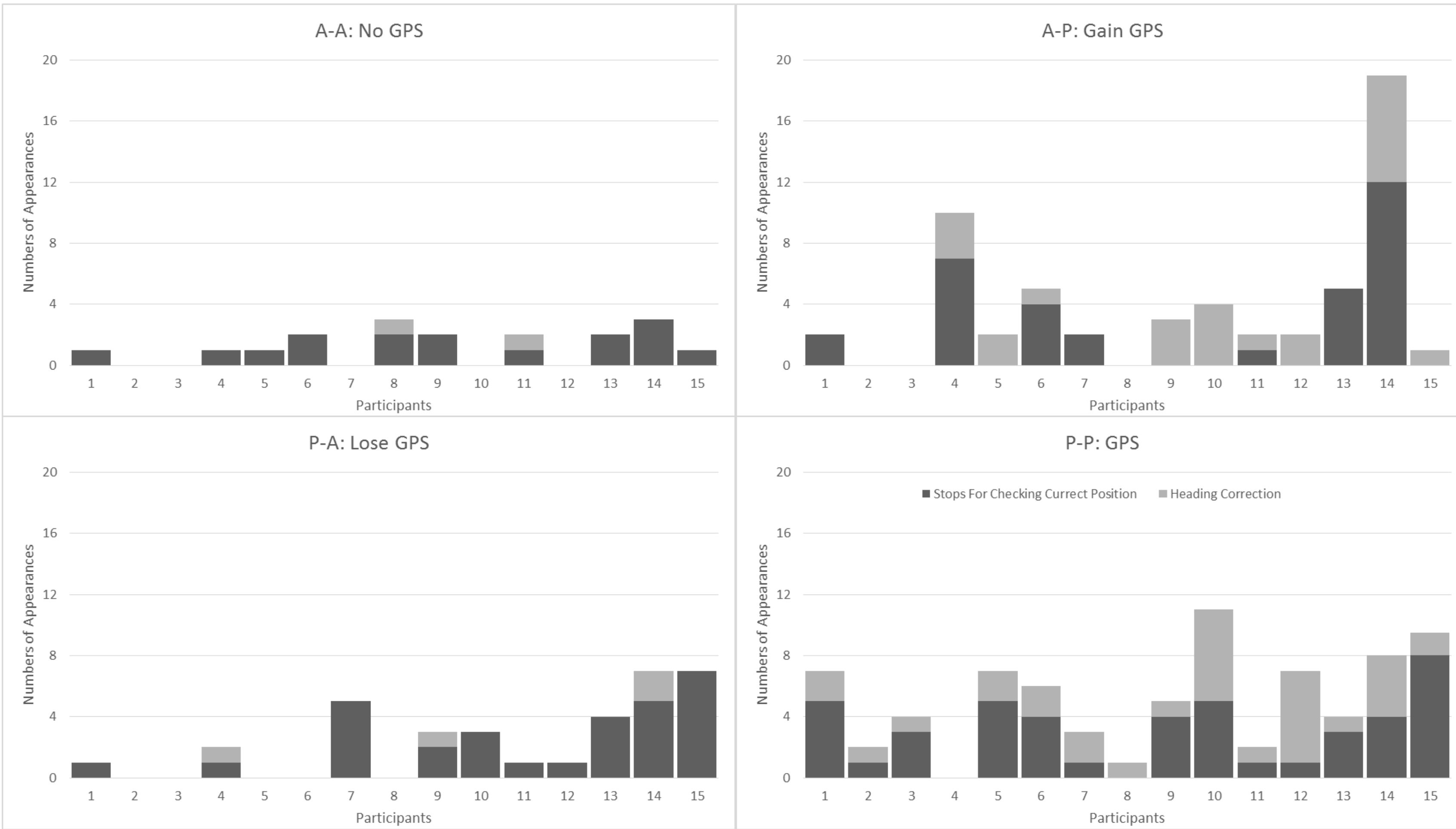


Figure 5.18 Number of stops and self-heading correction attempts in the second path

Many A-P participants made stops along the route where they compared dead-reckoning information between their own and GPS provided information. While the navigation condition of A-P participants changed from active to passive, path one had activated their active “system.” By contrast, P-P participants never experienced active navigation as they were supported by GPS for both paths. For this reason, they stopped more often before making decisions and carefully read spatial information from the GPS-display then toward to correct direction or rather continuously travel until GPS indicated they are out of the route (Figure 5.19).

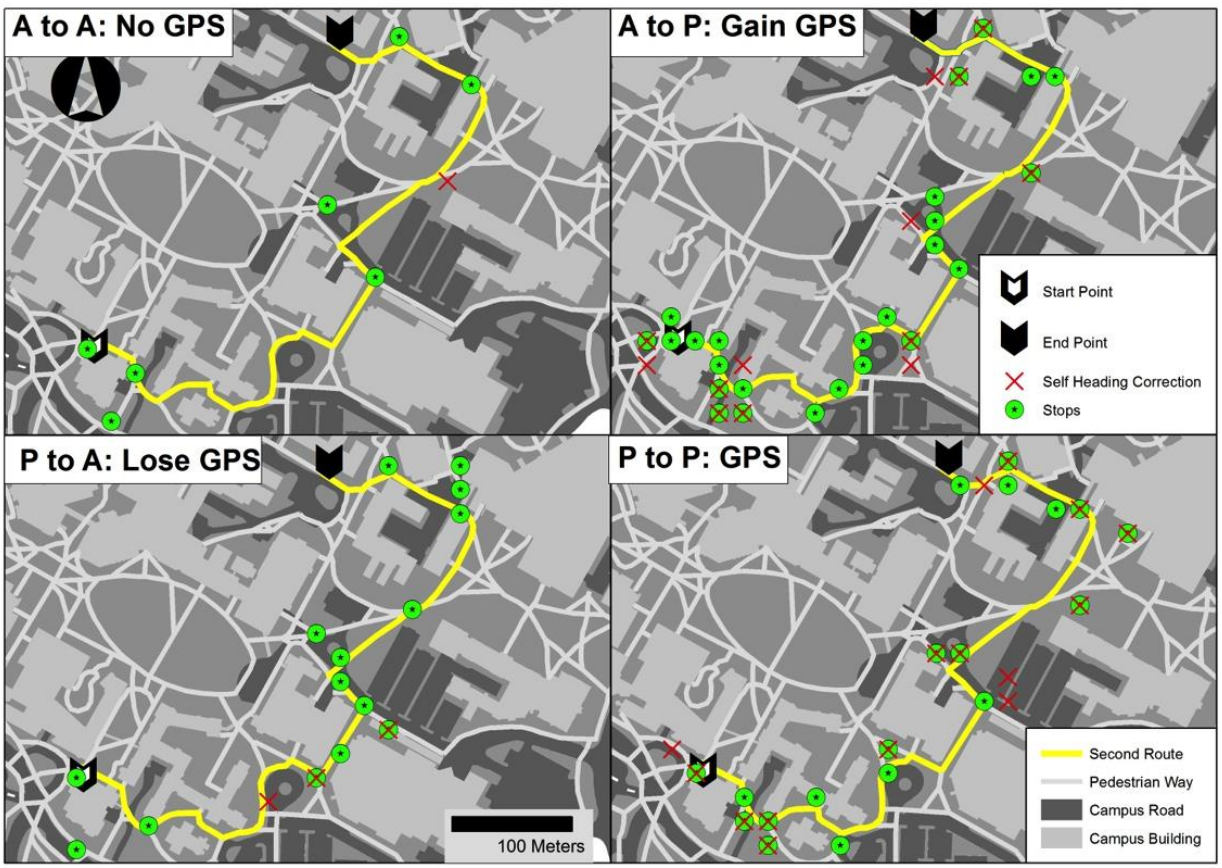


Figure 5.19 Stops and where participants corrected their heading in the second path

5.5.4 Decline in Route Awareness

Before beginning the navigation task participants were instructed to stay on the studied route (Figure 5.3) as close as possible. When participants were using GPS, they were always aware of the route and where they were in relation to it. By contrast, when participants did not have GPS, they had some trouble staying on route, so they required rerouting by the experimenter because their choice of off-route paths could lead them away from the path destination (Figure 5.20). If they kept following a wrong route, they would fail or give up the navigation task, in these cases the experimenter provided correct direction information and took them back to the route.

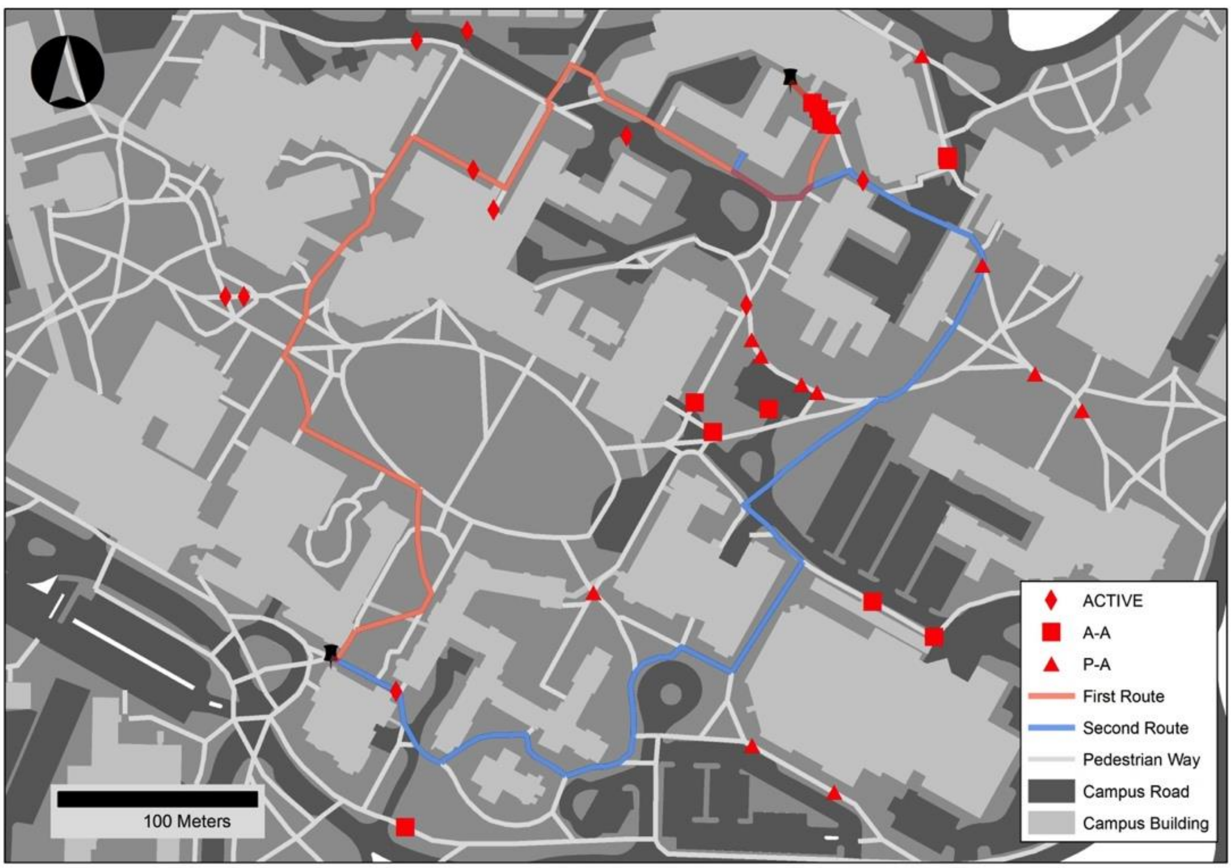


Figure 5.20 Location of correcting participants' heading by intervention

Participants exhibited a decline in route awareness on the second path (Table 5.7). This was most acute for participants who did not have the GPS. A-A and P-A participants experienced difficulty in clearly recalling the second path, causing frequent attempts to travel in the wrong direction. GPS participants did not require intervention by the experimenter. As GPS continuously updated the participant's current location on the display, they could correct their direction successfully based on the given spatial information.

Table 5.7 Number of required intervention by the experimenter

	First Path		Second Path			
	ACTIVE	**PASSIVE**	A-A	**A-P**	P-A	**P-P**
Appearance (%)	23	**0**	67	**0**	60	**0**
Number of Given Correction (Mean)	1.7	**0**	1.3	**0**	1.9	**0**

5.5.4.1 Vagueness of Heading

Most participants successfully reached the end point for the first path. Upon beginning the navigation tasks for the second path, many participants encountered difficulty in *establishing the correct initial direction*. This phenomenon was prevalent in participants who navigated the second navigation task without GPS (A-A & P-A, with approximately 50% of participants experiencing difficulty) (Figure 5.21).

Participants were observed to remain at the starting point of the second path for extended periods of time, with cautious visual exploration of possible paths. Most participants headed in the wrong direction (off-route) when beginning the second path. This uncertainty and route initiation difficulty may be explained by loss of spatial memory while navigating the first path. Navigation under A-P and P-P conditions (with GPS) resulted in few participants experiencing difficulty in determining the correct heading for the second path. This is likely attributed to the spatial information provided by the GPS device.

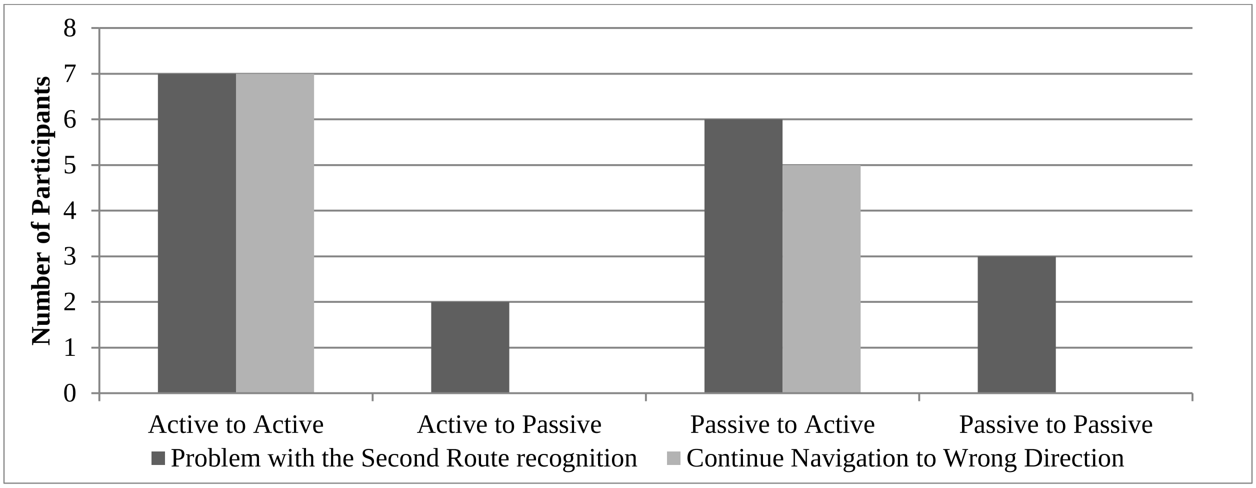


Figure 5.21 Number of participants with route initiation difficulty for the second path

5.5.4.2 Erroneous Destinations

When participants were using GPS for navigation, they had no noteworthy problems in recognizing their final destination. Approximately half of the participants who did not have GPS for the second path had a very hard time *recognizing their final destination*. They were very hesitant to state they had reached the final destination; some participants reduced their travel speed, stopped frequently, or confirmed the final destination location with the experimenter. Furthermore, some participants attempted to finish their second navigation take at the starting point of the first task (Figure 5.22).

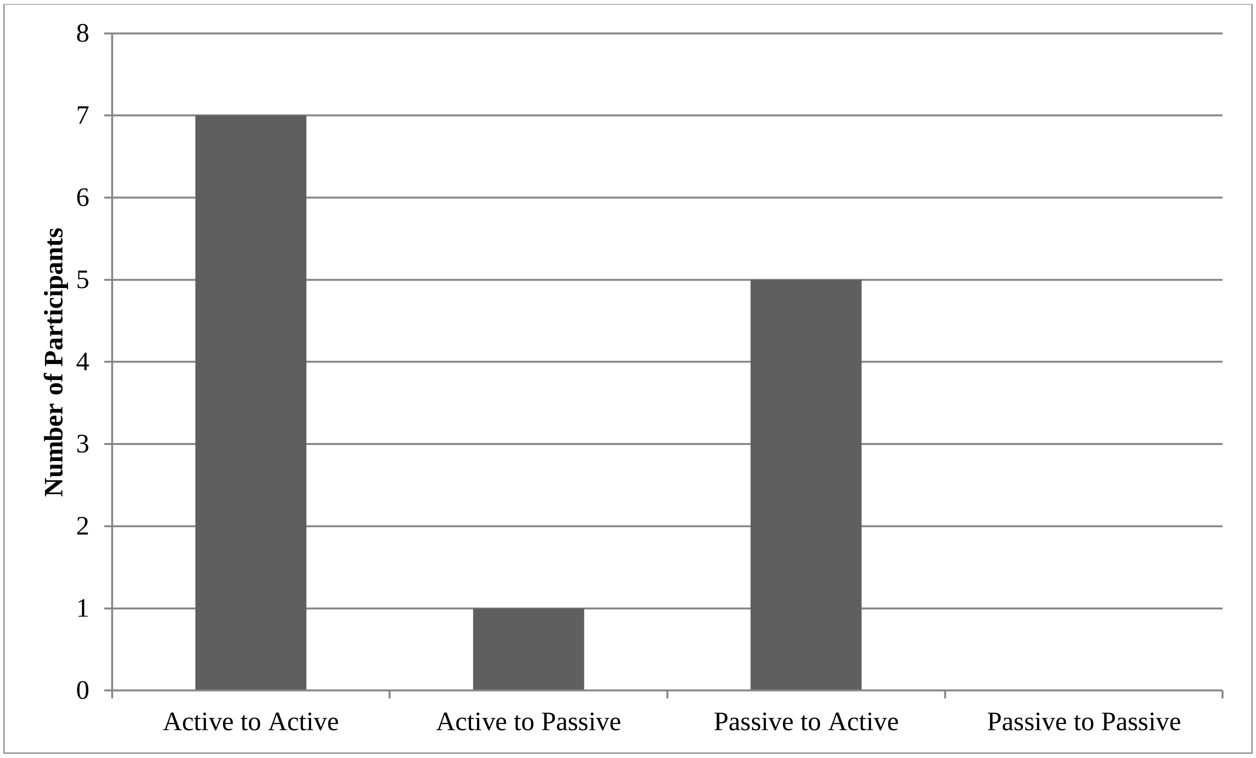


Figure 5.22 Number of participants hesitating to recognize the final destination

5.5.4.3 Hesitation on Current Location

During navigation, some participants tried to *confirm their current heading* with the experimenter. When GPS was not available, participants had less confidence in their current location even if their heading was correct. When GPS was unavailable participants had a tendency to *confirm their current heading* with the experimenter, travelling both correct and incorrect routes. In terms of GPS-based navigation, participant anxiety in travelling the correct route is reduced by GPS. Notably, female participants tended to ask more questions than male participants (Figure 5.23).

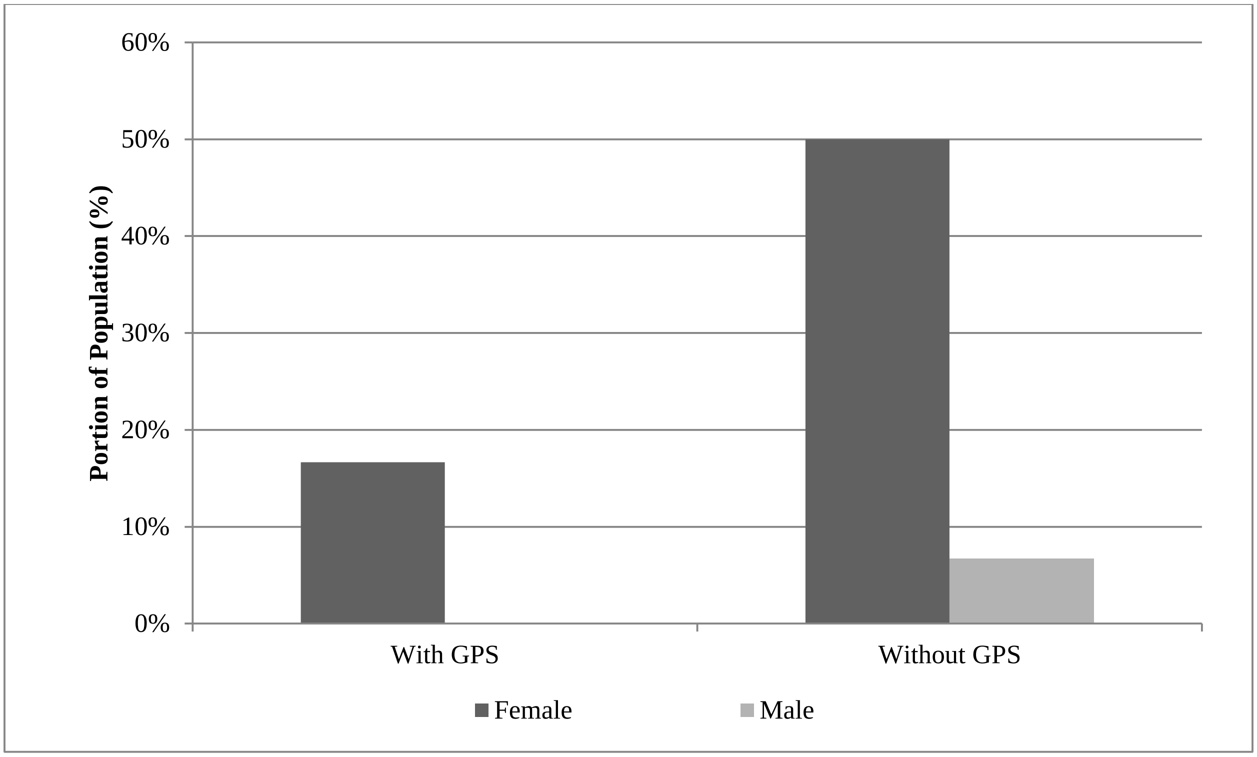


Figure 5.23 Proportion of questions asked based on sex
**Significantly difference results for number of questions asked by sex (ANOVA: all p-value<0.02)*

5.5.5 Overall Navigation Efficiency

There were substantial individual differences in *travel speed*, so this was not the best dependent variable in the study (Figure 5.24). Most participants navigated relatively faster on the second path. Interestingly, participants' relative navigation speeds were reduced at the corner "A" (Figure 5.24). This corner was the first major decision point and included two options that would not diminish their ability to reach the path destination; furthermore, their visual field was limited. Other than corner "A," ACTIVE participants navigated a consistent speed on path one, but PASSIVE participants had observable speed changes as they referred more often to the GPS unit.

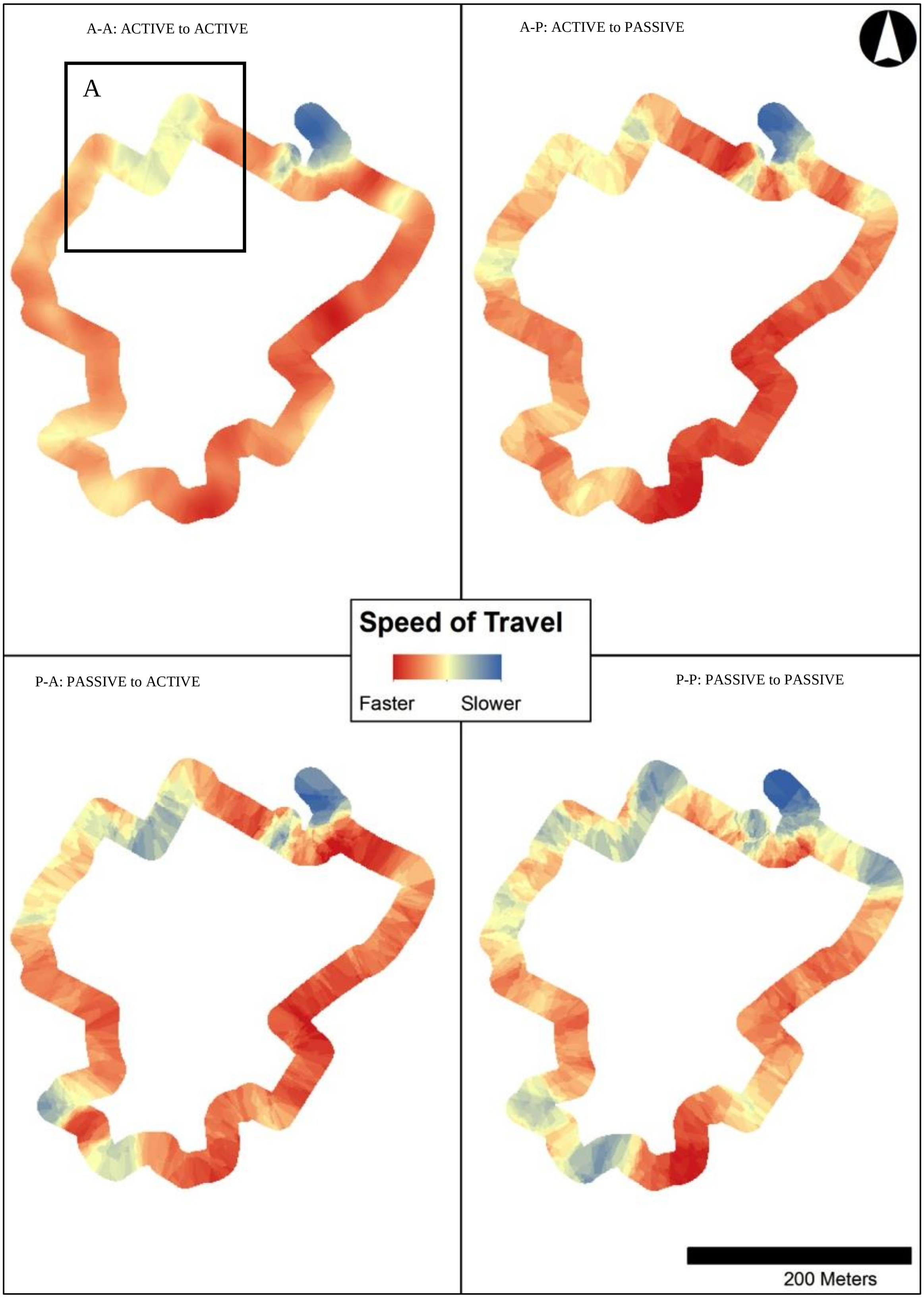


Figure 5.24 Travel speed trends by normalized speed of four navigation conditions

Navigation speed on the second path did not seem to be as clearly associated with the GPS, it seemed to be most associated with their previously adopted navigation behaviour. A-A and A-P participants had less speed changes but P-A and P-P showed inconsistent speed of travel in the second path. Once participants gained the GPS in the second path, their navigation speed became relatively faster at the same time their navigation confidence increased. *Travel distance* seemed better than speed for elucidating the degree to which participants correctly followed each path (Figure 5.25).

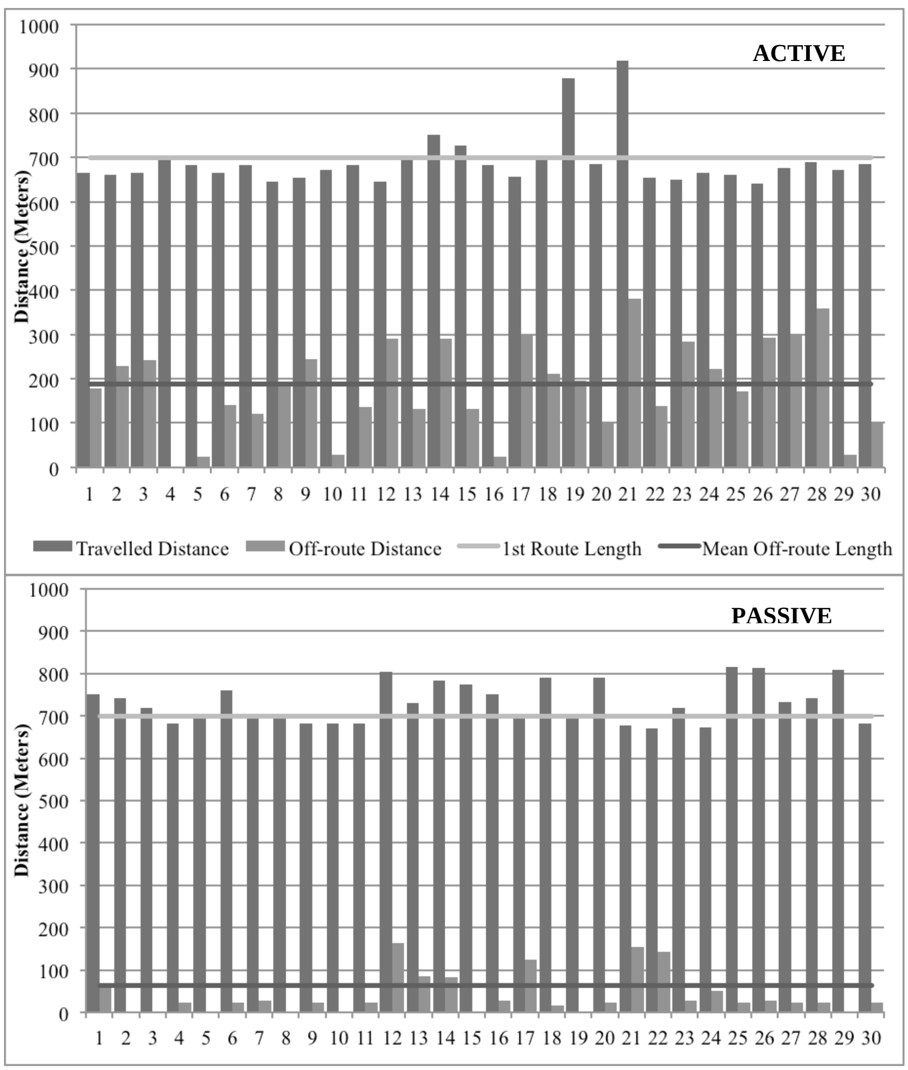


Figure 5.25 Travelled distance comparison in the first path

Mean distances greater than actual path lengths were achieved by participants travelling longer off-route or by frequently changing their heading to determine the correct route direction. Mean ACTIVE travel distance was shorter than the designated path length (due to shortcutting) (Table 5.8).

Table 5.8 Analysis of route metrics

	First Path (700m)		Second Path (740m)			
	ACTIVE	**PASSIVE**	**ACTIVE to ACTIVE**	**ACTIVE to PASSIVE**	**PASSIVE to ACTIVE**	**PASSIVE to PASSIVE**
Travel Distance (Mean)	689.72m	732.86m	827.35m	769.06m	882.37m	777.04m
Travel Distance (Std)	60.60m	47.48m	92.56m	38.16m	125.03m	59.08m
Travel Distance (Max)	918.60m	816.40m	1018.70m	858.10m	1179.90m	981.40m
Travel Distance (Min)	640.20m	670.10m	671.20m	725.90m	725.90m	738.80m
Travel Distance (Median)	673.55m	730.40m	850.30m	761.60m	858.90m	765.90m
Exceeded Travel Distance (%)	-1	5	12	4	19	5
Off-Route Taker (%)	100	73	100	53	100	33
Off-Route Distance (Mean)	189.06m	63.63m	239.95m	45.69m	222.86m	17.60m
Off-Route Distance (Std)	98.54m	29.74m	137.10m	27.19m	139.64m	9.76m
Off-Route Distance (Max)	380.55m	110.62m	479.88m	99.33m	476.76m	24.32m
Off-Route Distance (Min)	23.11m	14.45m	71.28m	19.77m	21.65m	5.52m
Off-Route Distance (Median)	190.46m	69.25m	251.01m	35.76m	182.87m	18.77m

Significantly difference results for both travelled distance and off-route length among different conditions (ANOVA: all p-value<0.01)

Figure 5.25, illustrates individual participant results for distance travelled under both ACTIVE and PASSIVE. ACTIVE participants tended to travel shorter distances than the actual experimental route length in path one, thus indicating participants' spatial knowledge and ACTIVE state made navigation more efficient. Even if ACTIVE participants showed frequent off-route travel, most of this was associated with shorter paths which reduced total travelled distance.

Despite a lower mean, ACTIVE participants maximum travel distance and standard deviation were both higher for off-route travel compared to PASSIVE participants. ACTIVE participants tended to deviate more from the prescribed route, causing heightened risk for travelling further distances. PASSIVE participants' route selection tended to be less deviant. Some PASSIVE participants utilized off-route shortcuts for the first path, perhaps attributable to low familiarity with GPS and relatively higher levels of trust in their cognitive map. For the second path, many A-A participants travelled further than the designated route length (12% increase), with off-route usage remaining high (Figure 5.26).

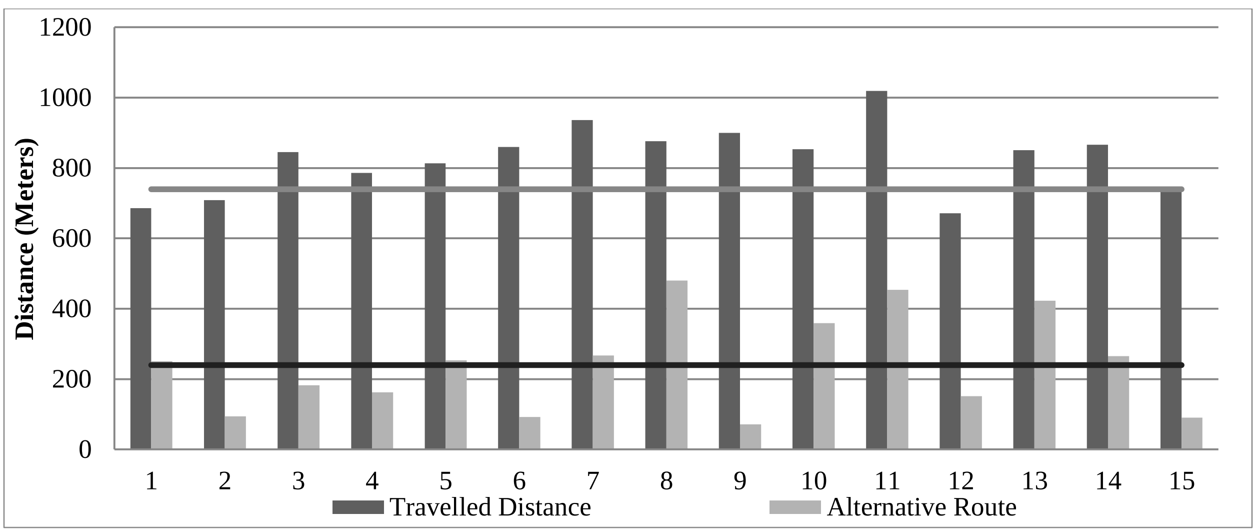


Figure 5.26 Travelled distance of A-A (Active to Active)

A-P participants tended to travel somewhat further on the second path, with off-route usage decreasing substantially (Figure 5.27). Navigation effectiveness of A-P participants did not decrease to the extent of A-A, as the GPS was available. Despite this, A-P participants tended to use more off-route paths compared to P-P participants. Under A-P conditions, where participant's navigation mode changed from active to passive, the level of GPS familiarity was expected to be lower. For this reason, these participants may not have been entirely dependent on the GPS device during navigation of the second path.

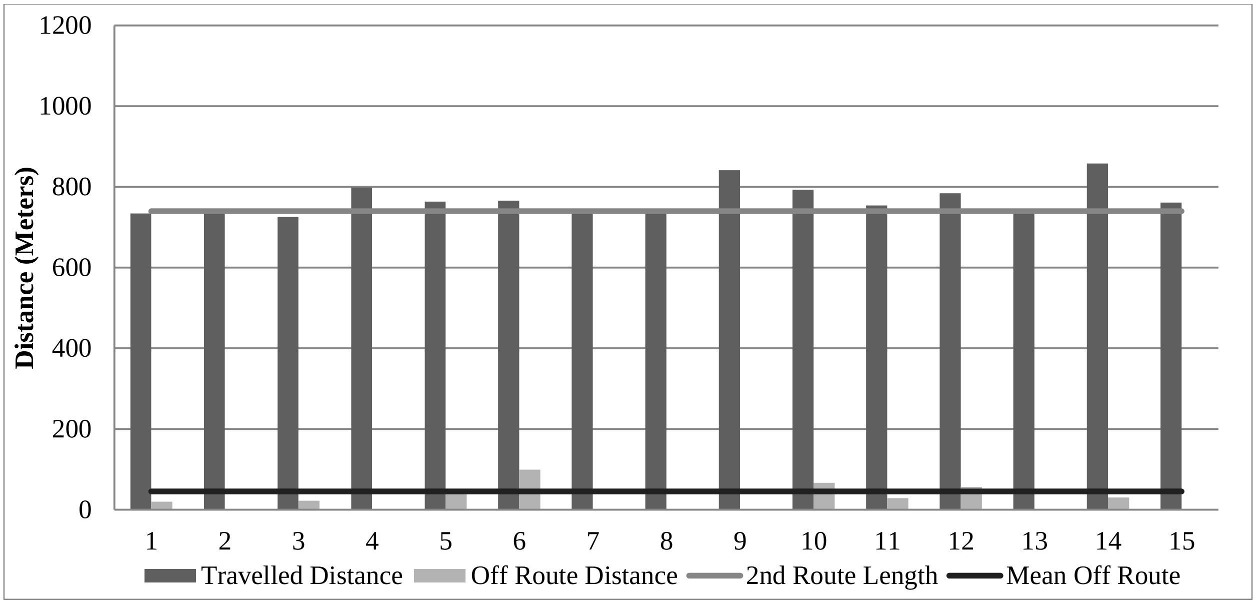


Figure 5.27 Travelled distance of A-P (Active to Passive)

When P-A participants lost access to the GPS device for the second path, they experienced difficulty in following the designated route. All participants traveled off-route, many of these episodes were associated with greater travel distance (Figure 5.28). When the GPS was taken away from P-A participants, their navigation effectiveness became similar to that of A-A participants. Little difference in navigation effectiveness was observed between the first and the second paths for the P-P condition (Figure 5.29). These participants followed more precisely the second path compared to the first path. The overall travelled distance for the second path was similar to the first path, however the mean off-route length and frequency of off-route travel was reduced.

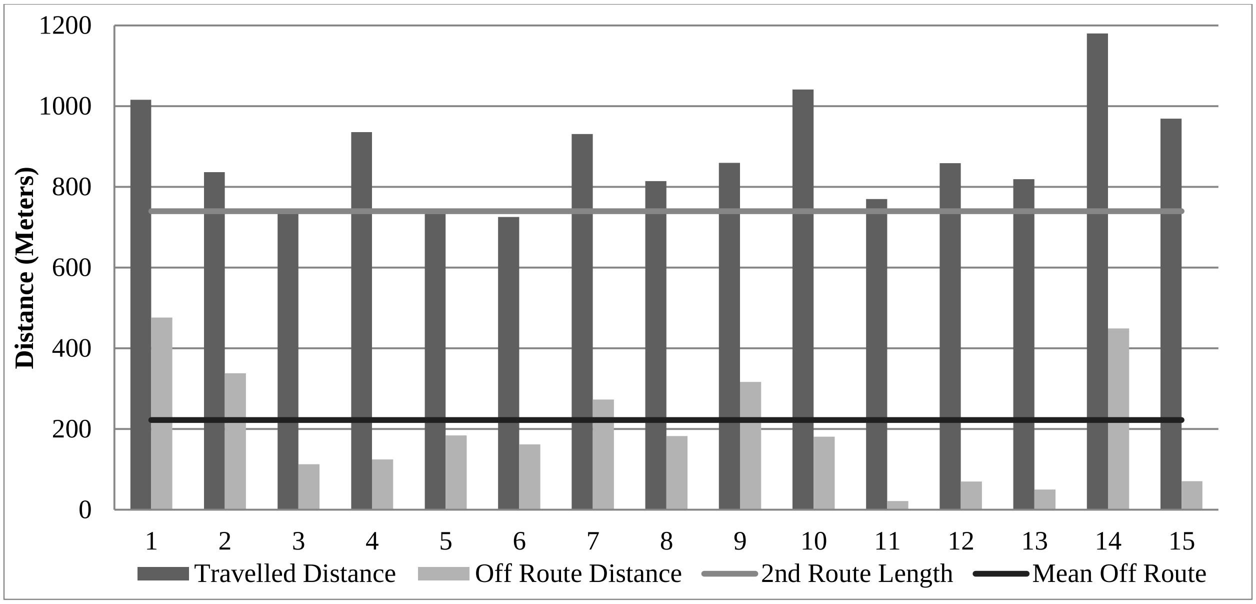


Figure 5.28 Travelled distance of P-A (Passive to Active)

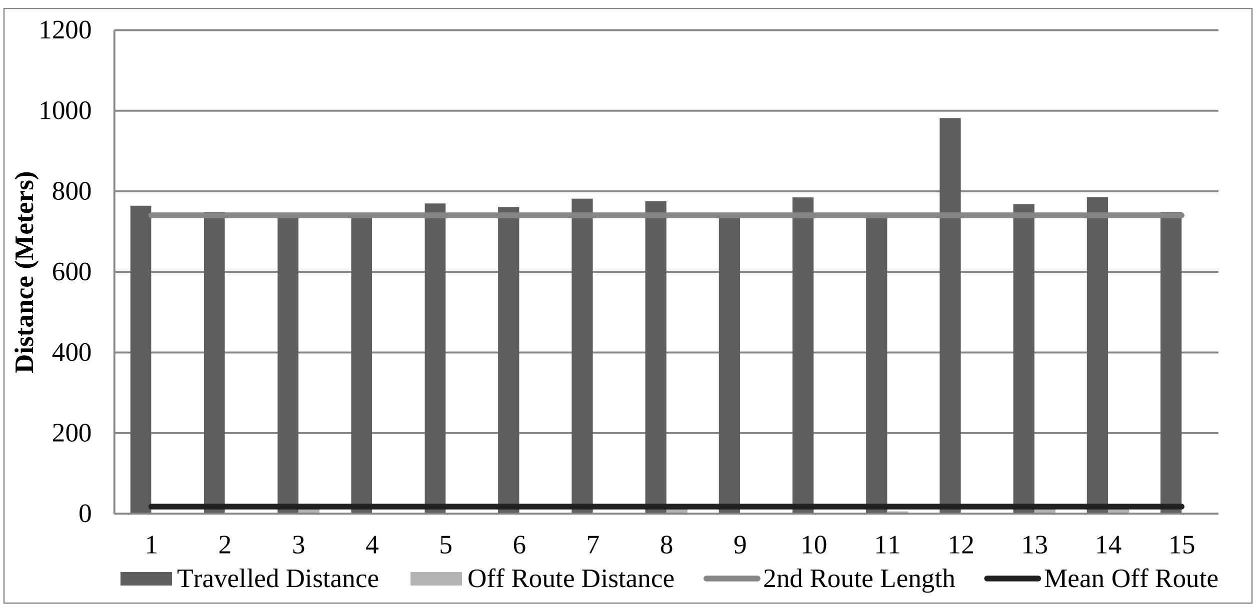


Figure 5.29 Travelled distance of P-P (Passive to Passive)

5.5.5.1 Raw GPS Tracking Comparison

Travel movement was also recorded with GPS for all participants. These tracking records allow a visual comparison of navigation performance (Figure 5.30).

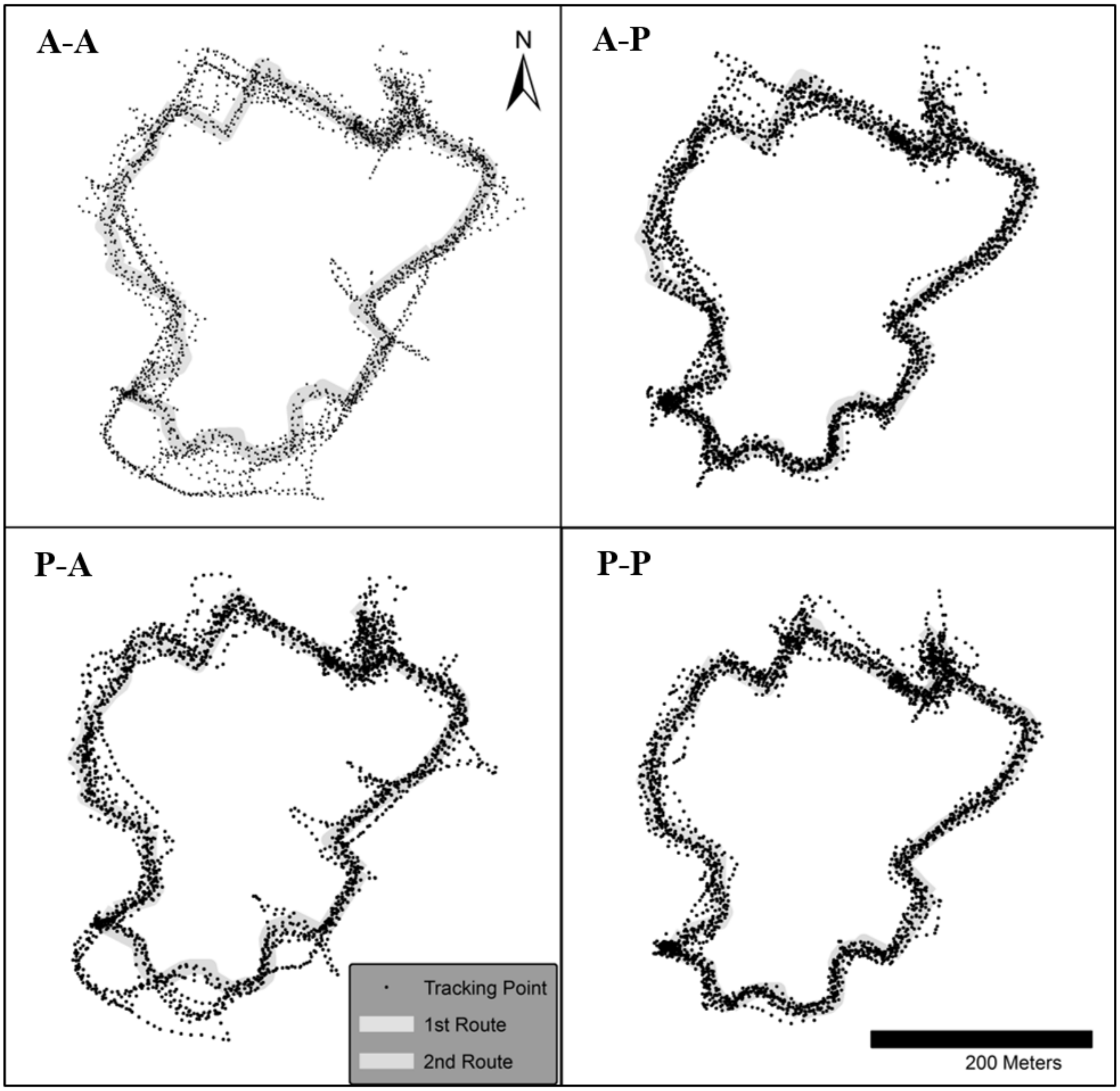


Figure 5.30 GPS tracking results comparisons for individual participants

When participants did not use GPS, the resulting route selection was quite variable. For these conditions, overall tracking records were wider and tended towards messier distributions. When participants had GPS available, their tracking records tended to be more concentrated within a narrow region; the GPS was able to guide participants to travel the designated routes. Interestingly, GPS support associated with the second path (A-P & P-P) resulted in better navigation performance over GPS support associated with the first path (P-A & P-P). This may be attributed to a higher level of familiarity with the GPS device, after using it for an extended period of time (P-P) or possibly the illogical nature of the first path. In combination, as A-P participants became more familiar with the experimental environment through their active "system," their navigation experience with GPS improved. From the perspective of measuring performance, the manual tracing of the route followed was more reliable than the GPS tracking. However, the GPS did support the generation of different visualizations (Figure 5.30).

5.5.6 Pointing Tasks

Following completion of both navigation tasks, participants were asked to point to 15 campus buildings along the experimental route (Table 5.9). A series of 15 individual pointing tasks were presented in a random order to each participant. All but one of the pointing targets could not be directly viewed by participants (Figure 5.31).

Table 5.9 Description of pointing targets

Building	Path	Pointing Target Description	Distance to Target (meter)	Angle to Target (degree)
Administration Building	2	Point to the Front Main Entrance of the Administration Building	210.83	185.10
Agriculture	1	Point to the Agriculture Main Entrance (South Side)	71.43	46.24
Archaeology Building	2	Point to the Entrance to Skywalk from Engineering to Archaeology	117.45	94.83
Athabasca Hall	2	Point to the South Side Entrance of Athabasca Hall (Near Faculty Club)	281.74	199.02
Biology Building	1	Point to the Entrance to Skywalk from Biology to Agriculture	121.28	270.47
Engineering Building	2	Point to the Entrance to Skywalk from Engineering to Agriculture	116.70	84.07
Faculty Club	2	Point to the Faculty Club	314.95	200.70
Kirk Hall 1	1&2	Point to the Kirk Hall Main Entrance	28.30	355.89
Kirk Hall 2	1	Point to the Entrance to Kirk Hall from Agriculture	68.48	17.60
Marquis Hall	1	Point to the University Bookstore	253.10	240.74
MUB	1&2	Point to the Memorial Union Building Main Entrance (Louis)	319.80	219.56
PAC	2	Point to the Middle of the PAC Front Main Entrance	291.31	172.96
Place Riel	1	Point to the Front Entrance of Place Riel (Bus Loop Entrance)	347.15	237.54
Saskatchewan Hall	1	Point to the Hospitality Service Entrance in the Saskatchewan Hall	275.51	214.59
Thorvaldson Building	1	Point to the Entrance to Skywalk from Geology to Thorvaldson	194.25	260.52

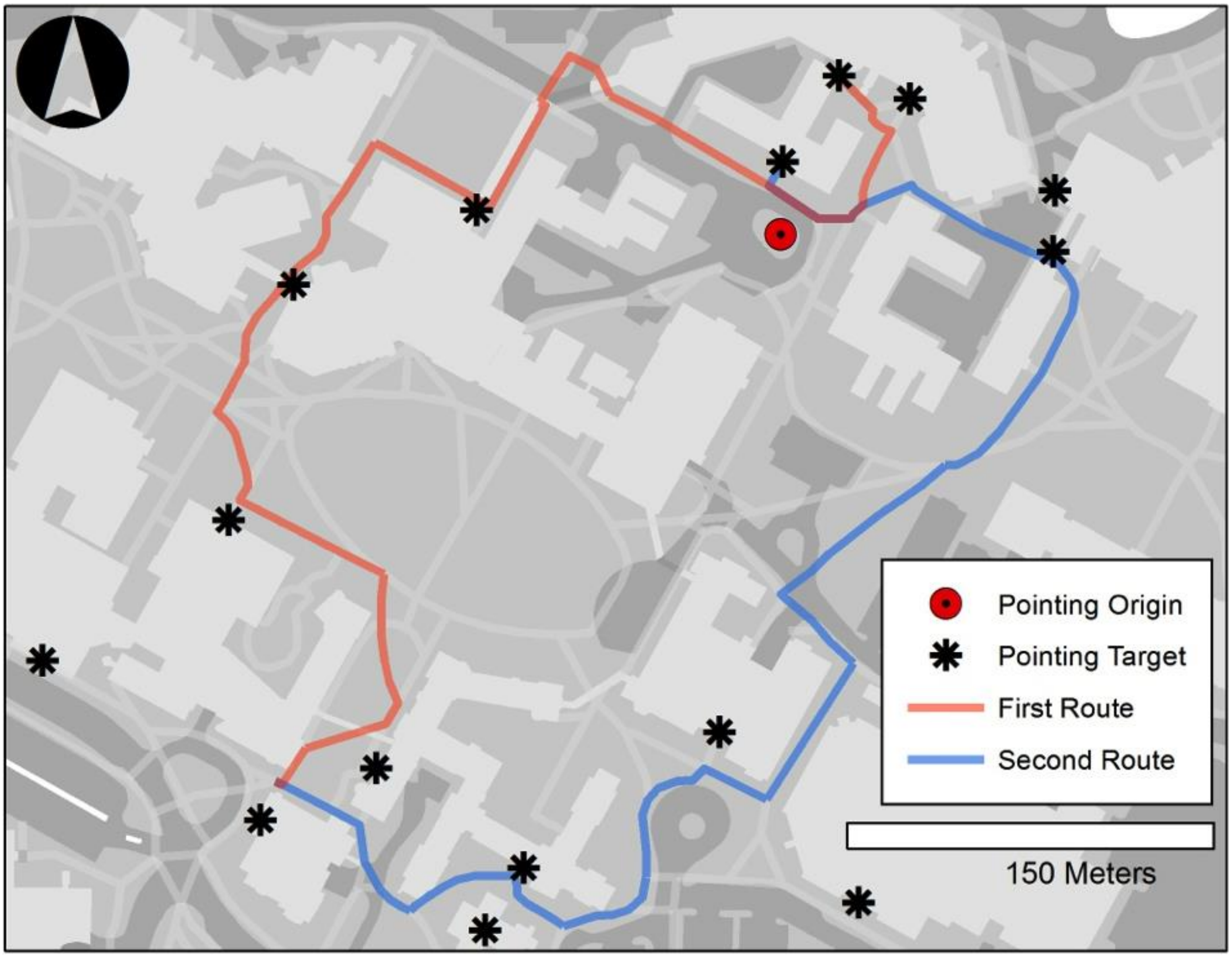


Figure 5.31 Fifteen locations of pointing targets

The difference between actual building location and participants pointing direction were compared based on the four different navigational conditions (Figure 5.32). It was noted that a change in navigation mode (i.e. active to passive, or vice versa) resulted in better pointing task performance. When the mode of navigation changed, participants became more familiar with their relative location and associated landmarks on the route. Euclidean distance from the pointing origin to the targets did not affect accuracy (Figure 5.33) but when pointing targets became closer, participants' painting results deviated to the right of the targets (Figure 5.34).

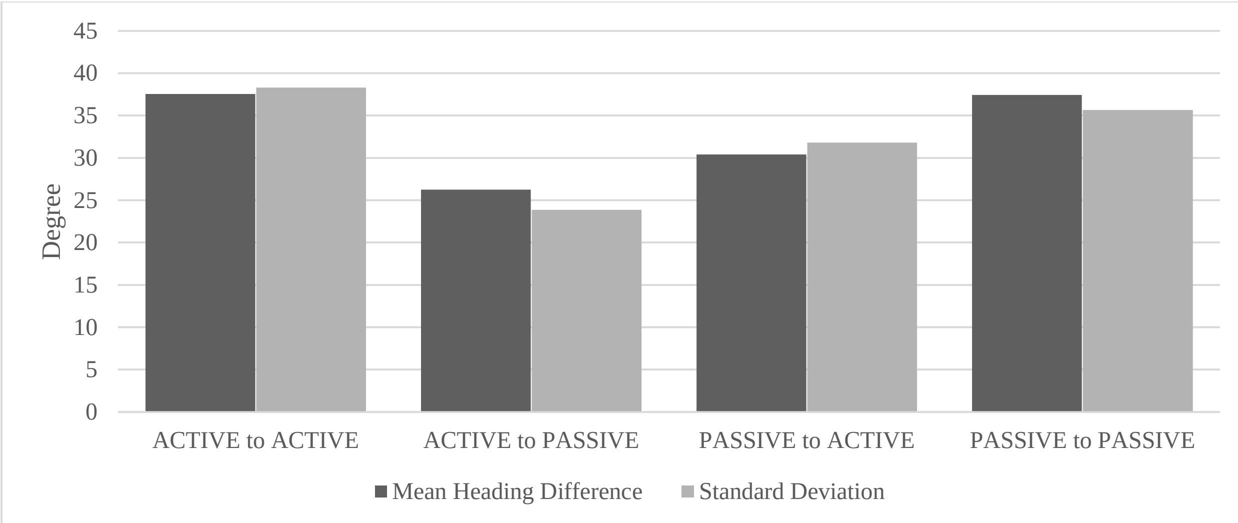


Figure 5.32 Pointing task results comparison
** Statistically significantly difference in pointing angle difference among conditions (ANOVA: p-value<0.01)*

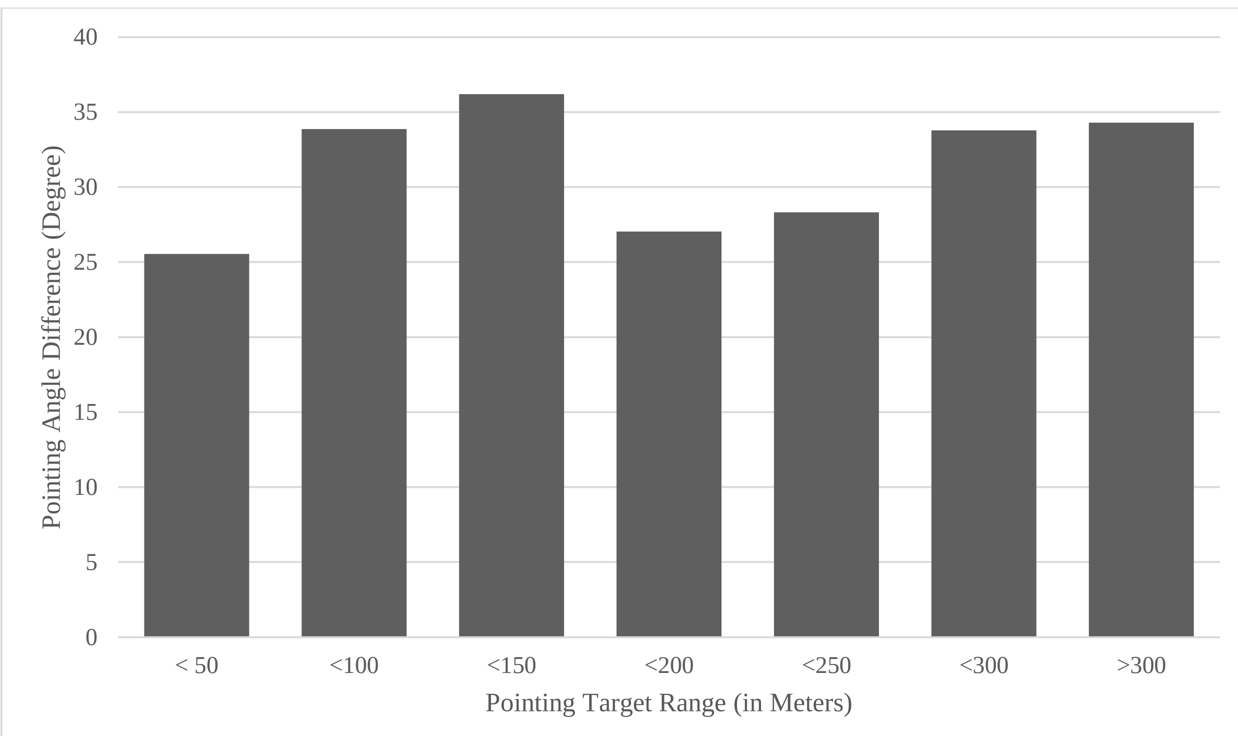


Figure 5.33 Pointing angle difference by distance

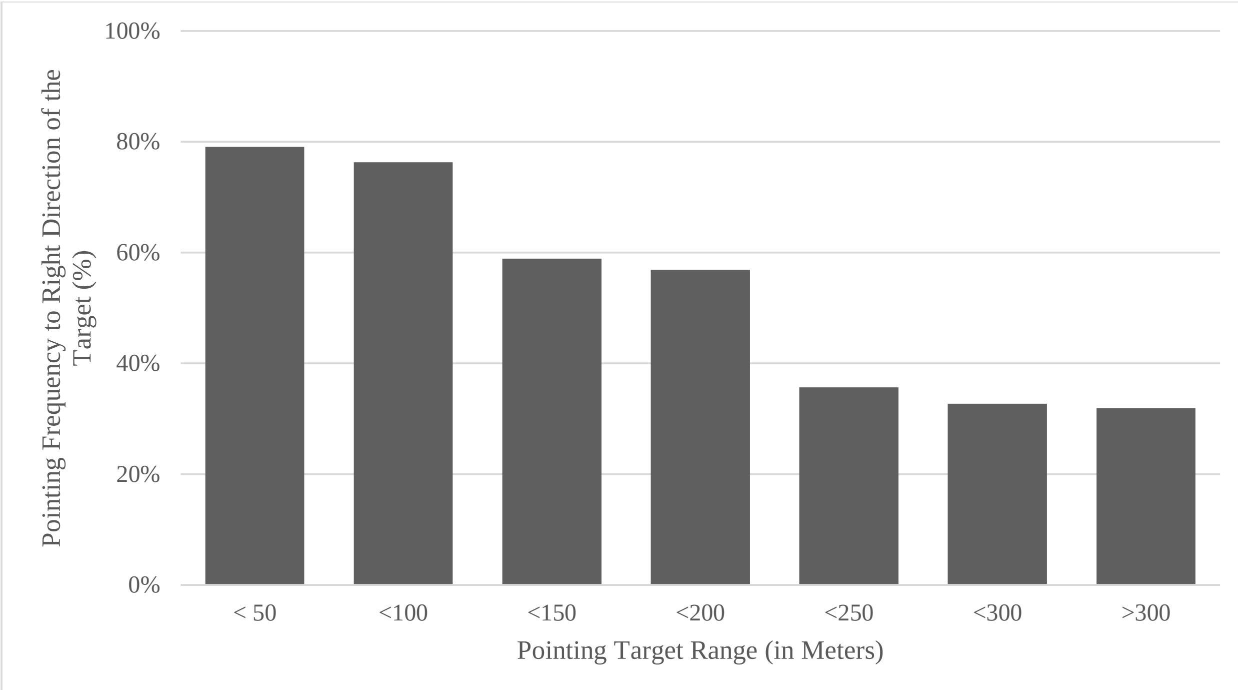


Figure 5.34 Pointing direction frequency by distance

5.5.7 Post Survey

Most participants believed they had followed the designated route. Despite this, differences in opinion were observed based on the availability of GPS. When participants were given the GPS for the second path, they tended to be more satisfied with their navigation performance compared with participants who did not (Figure 5.35). Additionally, participants who acquired a GPS device experienced no difficulties in recognizing the orientation of the second path from the starting point, were able to correctly identify the final destination for paths, and tended to display high confidence in the usage of GPS for navigation. By contrast, hesitations in recognizing the final destination caused participants who did not have the GPS in the second path were associated with reduced navigation confidence. Participants were also questioned regarding personal improvement in spatial knowledge regarding the UofS campus as a result of the experiment; half of all participants believed that their spatial knowledge regarding the UofS campus had increased. Interestingly, participants who experienced a switch from active to passive navigation considered GPS to be more helpful and expressed high confidence on their navigation performance; however these participants also demonstrated lower indications of improvement in spatial knowledge regarding the UofS campus when compared with participants in other conditions.

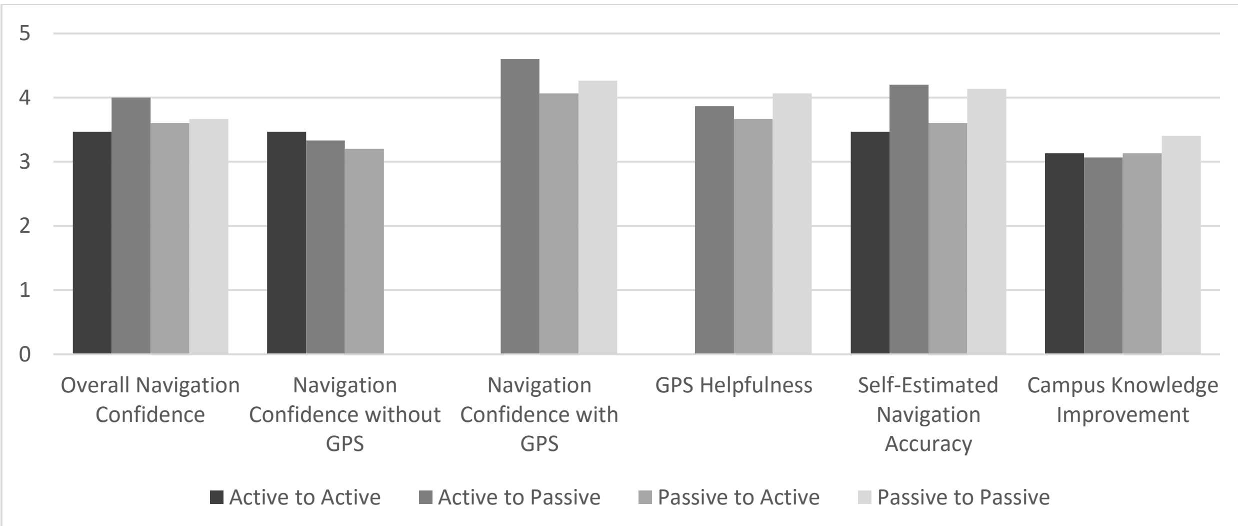


Figure 5.35 Post-survey analysis by navigational conditions

5.5.8 Sketch map Analysis

Most participants remembered their route after the experiment, perhaps because they already had some spatial knowledge of the UofS campus before entering this experiment. However, participants who did not have the GPS for the entire experiment struggled to recognize how many turns they made during the experiment (Figure 5.36). Furthermore, most participants did not have a problem recognizing the starting and ending locations. Many participants who did not have the GPS for the entire experiment had trouble recognizing the ending location of the first path (same as the starting location of the second path).

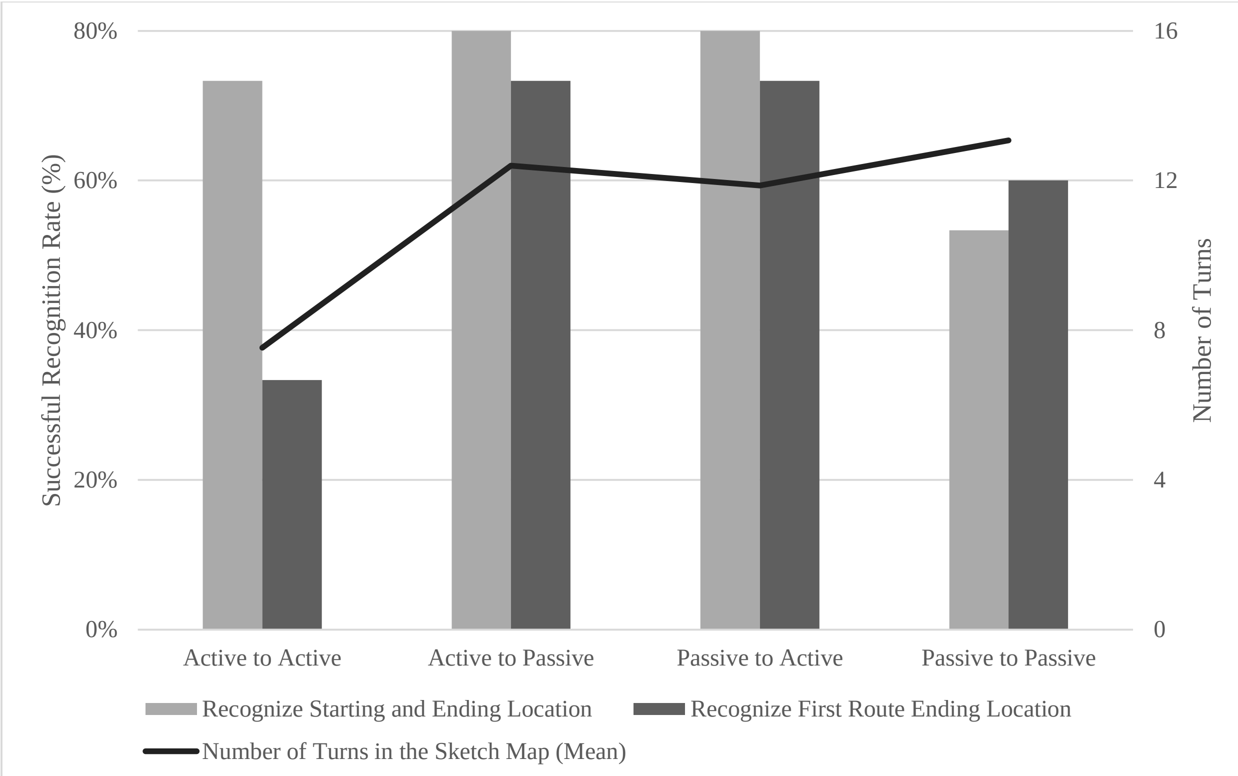


Figure 5.36 Sketch map analysis results I: number of turns and starting and ending location recognition

Overall drawing quality of sketch maps for all participants were not considerably different for the first path. When participants had the GPS for the second path, a majority of them indicated they traveled a path not consistent with the experimental path even if their actual travel followed the correct path (Figure 5.37; Box A). Many participants who did not have the GPS for the second path frequently traveled off-route from the second path starting location and they sketched their off-route as a traveled route (Figure 5.37; Box B).

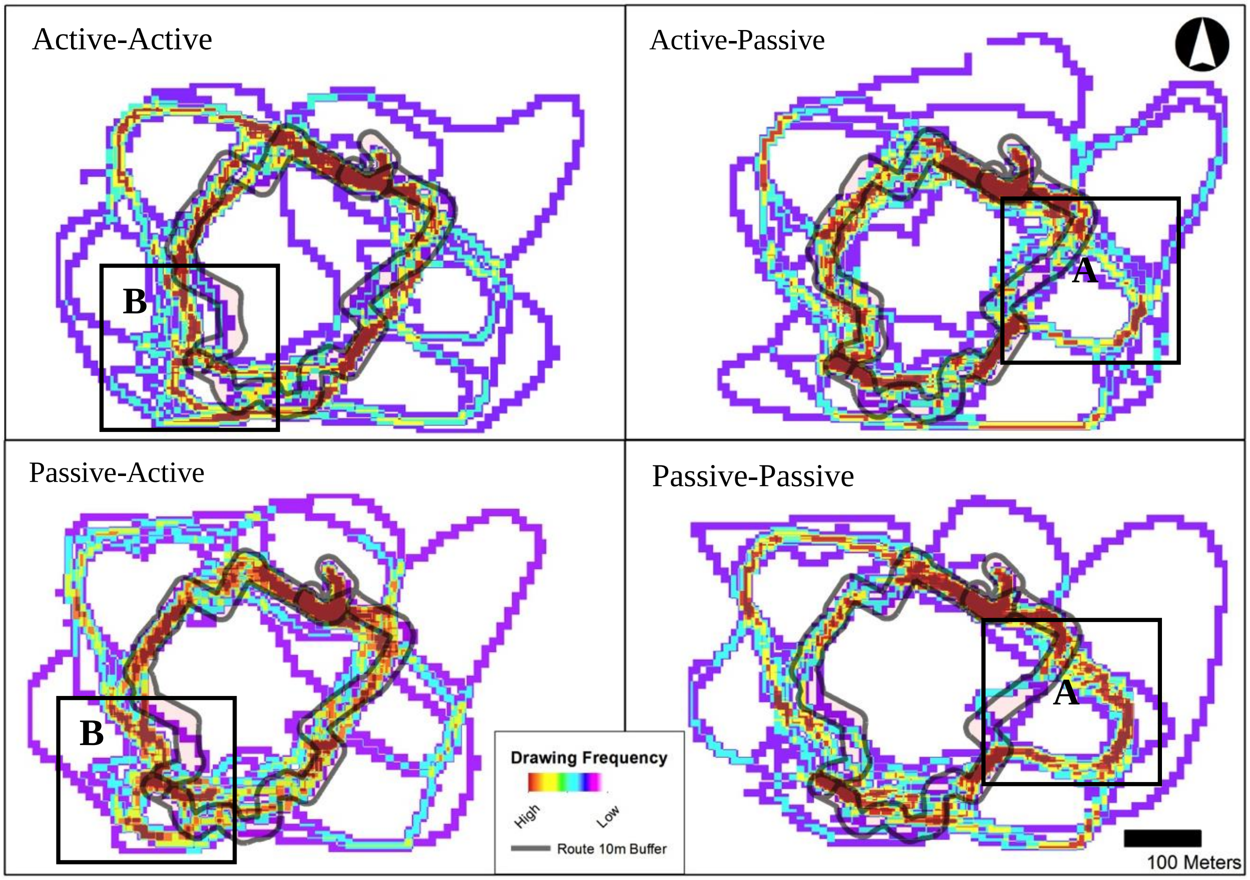


Figure 5.37 Sketch map analysis results II: comparison of most frequently recognized path among participants

5.5.9 Summary of Results

The presence of GPS did not result in a drastic enhancement in human navigation, but did have an effect on participants who were subjected to similar navigational conditions. However, GPS helped to prevent off-route travel and many associated risks (Table 5.10). GPS-based navigation assistance could help individuals save time although it does not guarantee optimal or preferred navigation.

Table 5.10 Navigation characteristics by different navigation conditions

	First Path		Second Path			
	Active	**Passive**	**Active**	**To Passive**	**To Active**	**Passive**
Spatial Awareness	High	High	Low	High	Low	High
Association with own Navigation Strategies	High	Medium	High	Medium	High	Low
Navigation Efficiency (Distance)	High	Medium	Low	High	Low	High
Dependency on the Navigation System		Medium		Medium		High
Risk: Travel Further Distance	Medium	Medium	High	Low	High	Low
Risk: Being Lost Momently	Low	Medium	High	Low	High	Low
Off-Route Appearance	High	Low	High	Low	High	Low
Destination Recognition	High	Medium	Medium	High	Medium	High

5.5.9.1 Navigation Condition 1 (Active to Active: No GPS support for the entire route)

Participants expressed better navigation effectiveness in terms of travel distance and shortcut usage in the first path. Pre-developed navigation strategies based on studying the map the navigation task allowed for sufficient knowledge to navigate of the displayed route, however these participants tended to use alternative routes (off-routes) based on their own spatial reasoning. As a result, these participants frequently took shorter paths to reach the first experimental destination. In contrast, for the second path, off-route segments were longer, causing an overall increase in total travel distance. One could argue that spatial knowledge was incomplete and affected navigation. As well, these participants experienced difficulty in maintaining the correct direction as specified by the experimental route. However, they remembered their travelled paths even if they travelled off-route, with the exception of struggling to recall the number of turns they made during navigation. In conclusion, active navigation promises efficient and effective navigation based on spatial reasoning; however, a decline in navigation performance can be related to poor route awareness. If they travelled over a short time and distance, their navigation is efficient, but if their travel is associated with numerous stops or multiple destinations which extend their travel time, they would be faced with greater risk of spatial anxiety or ineffective travel consequences.

5.5.9.2 Navigation Condition 4 (Passive to Passive: GPS support for the entire route)

Participants presented relatively better navigation effectiveness in the second path, perhaps due to increased familiarity with GPS navigation. For the first path, despite having a GPS device available, participants might not have been paying attention to the GPS or didn't understand the spatial configuration of the paths as represented on the GPS. As a result, participants experienced some difficulty in precisely following the designated experimental route, causing increased utilization of off-route paths with frequent stops to compare their current location with that of the GPS.

For the second path, participants were able to pay more attention to, or better understand GPS-specified information, which resulted in less off-route travel. In situations where participants paid a great deal of attention to the GPS, rather than personal spatial knowledge, many corrections were observed. Despite a high number of corrections, continuous GPS support may have kept spatial anxiety low, resulting in high participant satisfaction with their navigation performance. Interestingly, many participants recognized differently between the actual path and the path represented in their cognitive map. In brief, passive navigation could help the navigator stay on route, so if the navigator had sufficient experience with the GPS device, their navigation was effective as long as the GPS-device was available. But, if they are travelling in the future in the same environment, they are likely to have the trouble recognizing the correct path without the GPS.

5.5.9.3 Navigation Condition 2 (Active to Passive: 1st Path: no GPS and 2nd Path: GPS)

Similar navigation patterns were observed for both groups who did not have a GPS for the first path. For P-P participants, navigation efficiency improved on path two since their understanding about GPS-specific spatial information had been improved. However, despite low familiarity with the GPS for active to passive participants (A-P), navigation performance on the second path was comparable to the performance observed for condition 4 (PASSIVE – PASSIVE). Low familiarity with the GPS device may have been compensated by participants' high spatial awareness about their surroundings and high confidence on their navigation performance. They were very satisfied with their overall navigation performance, when they obtained the GPS-device they felt well supported and performed navigation with confidence. As a result, their relative travel speed increased for the second path.

For the second path, the GPS-device provided complementary spatial information that helped overcome the loss of spatial memory over time. During active navigation, they depended on dead reckoning and their recall of the map, helping them understand their current location on the GPS device. However, they did stop more frequently where path connectivity and complexity increased. When navigation condition switched from active to passive (gained GPS), participants may have experienced cognitive disagreement between the route in their head and what was indicated on the GPS, resulting in a higher proportion of off-route travel. Personal spatial understanding may be a supplementary factor available to maximize a positive GPS experience without relying on device familiarity. These participants tended to be satisfied with their navigation experience, but did not consider their personal spatial knowledge to be improved.

5.5.9.4 Navigation Condition 3 (Passive to Active: 1st Path: GPS and 2nd Path: no GPS)

When participants used the GPS in the first path, there is no obvious difference between navigation condition 3 and 4, which was expected. Navigation effectiveness on the second path was quite different. Despite navigation performance in the second path correlating well with participants of the navigation condition 1, participants experienced much higher uncertainty in recognizing their path and made frequent stops, like other passive participants. As a result, participants' navigation effectiveness was reduced when they lost the GPS, so relatively higher rate of off-route travel was observed for the second path. Their loss of GPS-support ended up increasing their spatial anxiety and reducing their navigation confidence.

5.5.9.5 Impact of the availability of the navigation system

Figure 5.38 shows a possible initial mental model based on the availability of the navigation system. For navigation, individuals have their own understanding of the environment, but if their cognitive map is not complete, they are more likely to experience navigation problems. When no navigation system is available, individuals depend on their cognitive map. A good cognitive map is composed of a memory for places and the absolute and relative arrangement of those places.

The GPS-based navigation system supports individuals' navigation, but might be influenced by the level of familiarity with the navigation system. One of the main concerns is that when individuals have a positive experience with a navigation system, their level of the dependency on the navigation system goes up. This dependency could support navigation but will reduce the level of cognitive understanding of the experienced environment. Losing navigation support can lead to anxiety and navigation will be harder.

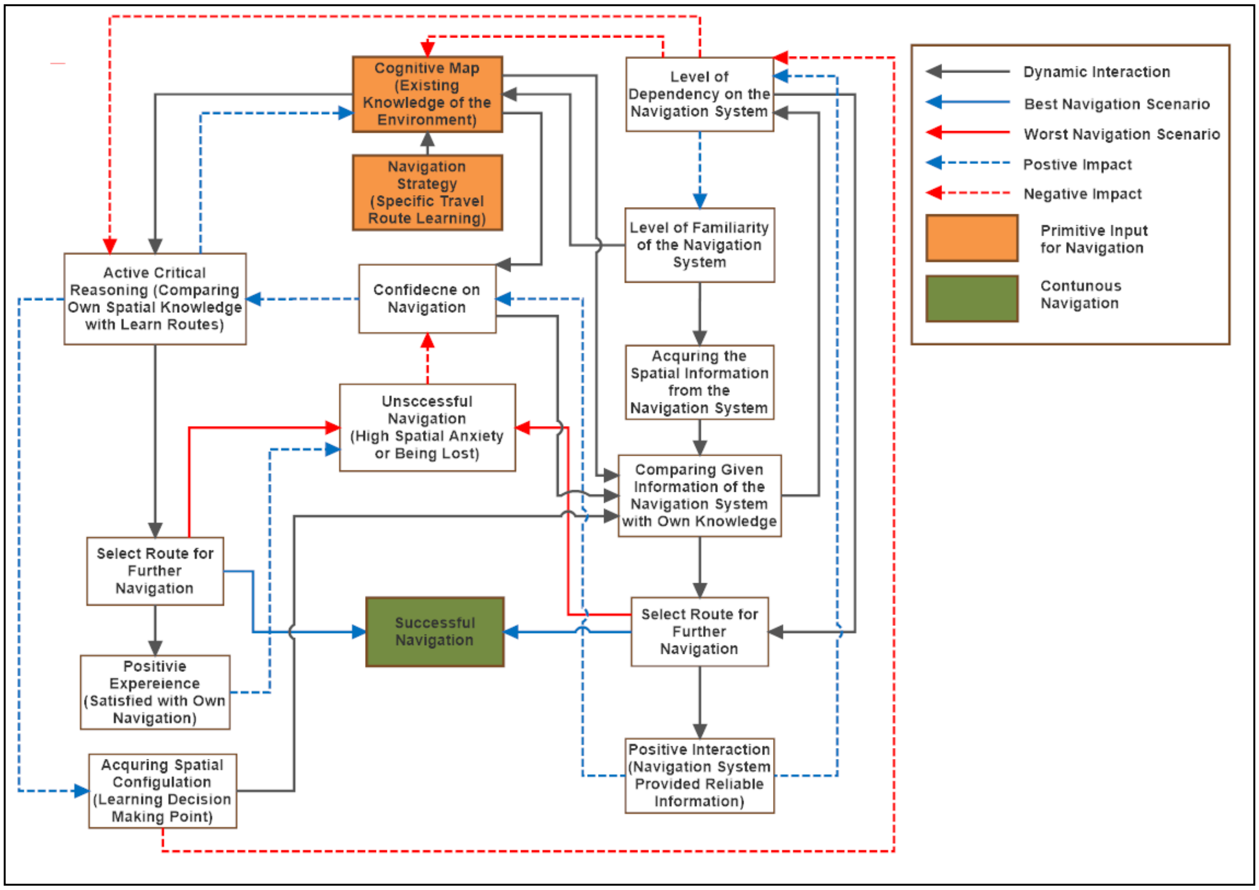


Figure 5.38 Initial interaction between navigation and the availability of the navigation system

5.6 CONCLUSION

Based on the results of this research, GPS improves navigation in unfamiliar environments. However this improvement is limited to specifically followed routes and the portions of the environment through which they pass. Passive navigation is beneficial when more complete spatial knowledge is a goal, as it supports fast decision making during navigation after individuals actively interact with their surroundings. Their experience during active navigation helps them learn about where they need to make decisions and overcome changes in the environment. GPS could be a complementary source for gaps in their cognitive map.

Both active and passive navigation modes have the potential to benefit our daily navigation experience. However, it is important to understand how these modes of navigation are associated and what primitive requirements must be satisfied in order to maximize our navigation experiences (Table 5.11).

Table 5.11 Impact of the availability of GPS assistant on human navigation

	Active (No GPS)	**Passive (GPS)**
Critical Requirement	Degree of familiarity with ***surroundings***	Degree of familiarity with ***navigation system***
Positive Impact	Dynamic navigation strategy (high flexibility for route selection)	May result in increased navigation performance over time
Negative Impact	May result in decreased navigation performance over time	Fixed navigation strategy (less flexibility for route selection)
System Availability (Navigation Mode Change)	If experiencing GPS loss (To Active): anxiety level may increase	If experiencing GPS gain (To Passive): GPS could be used as complementary source for covering their knowledge gap (loss of memory) in the space
Route Recognition	Relatively better memory on the experience route or associated landmarks	Negative impact on understanding scale of the experience route or associated landmarks
Mode Recommendation	Travel in the novel environment in relatively shorter period time, instant movement or need to be an expert (commuter)	Travel in the novel environment in relatively longer period of time and just a visitor / tourist

Individuals can accomplish successful and efficient navigation without GPS, but if participants make mistakes during travel, the overall travel distance could increase and the time needed to determine the correct heading might also rise. In order to function in a new environment we need to familiarize ourselves with our surroundings before traveling. GPS assistance may help people to save time in this process and can assure navigation success. It is also capable of reducing disorientation and unnecessary travel, such as taking off-route paths. In order to have a successful navigation experience with GPS, we need to be familiar with guidance style of the GPS or have a spatial knowledge of the environmental surroundings.

As previously mentioned the GPS could support incomplete spatial knowledge that spatial memory and actual environmental configuration are not matching. However, human's spatial knowledge is hard to be discontinued in sudden but GPS support could be discontinued in sudden by various technical issues. If GPS support is not seamlessly available, user experience would be varied by when gain or lose GPS support. In this research found that when participants experienced unexpected absence of GPS support during navigation, they frequently and repeatedly exposed to high risk of losing the ability to maintain correct heading and their confidence on using a navigation system was reduced. This result supports one of the previous research that when an individual has a negative experience with a navigation system, the individual's trust of the navigation system may decrease (Wei & Bell, 2012).

In other way, when participants experienced to gain unanticipated GPS support in the middle of navigation, their confidence on the navigation system were improved. Interestingly, participants could use the GPS efficiently even if participants were not have prior experience with the navigation system. This result suggested that active navigation experience provided notion that what information was needed to obtain from given GPS support for maintaining correct heading. These findings provide contemporary assessment of using the navigation system that what is benefit to use the navigation system, how individuals reacts during the navigation system's status changes (i.e absence to present), and when the navigation system becomes the most efficient navigation tool for understanding spatial relationship between self, landscapes, and space.

We often find gaining spatial knowledge about natural environments more challenging than built environments because of a lack of applicable, unique information about features (Kaplan, 1976). However, GPS can provide very reliable positioning (longitude, latitude, and altitude) for outdoor environments (Borriello et al., 2005). It can provide absolute location immediately and relative location on an associated map. People can use this for hiking or research purposes in most outdoor environments. GPS also has potential for use in urban areas besides navigation and wayfinding (Kaplan, Wheeler, & Holloway, 2004). For example, navigation systems provide an ideal route to a destination while avoiding high traffic and unsecure areas; it can also provide useful urban information to the traveler or shopper. When first arriving in a new area, we generally need to spend some time becoming familiar with the local physical landscape. In contrast, once we become familiar with an urban setting, predicting the configuration and composition in that urban environment is relatively easy because many streets cross at right angles and there are many unique visual aids, such as signs.

Our navigation skills are not fully dependent on navigation tools. Navigation in well-known and well-traveled environments is often accomplished without the use of maps, GPS, or other tools and is typically governed by basic travel needs (Blades, 1993). Travelling certain routes repeatedly allows us to become experts in the environment (Allen, 1999). As well, we may gain spatial knowledge through indirect methods, such as maps, web-based guidance, and verbal or written communication. Presently, more diverse environments exist than ever before. Because of this, the development of adjusted navigation strategies for various needs and requirements should be a priority. Traditional methods may help us overcome some navigation challenges, however these are often high cost (time), spatial anxiety, and the possibility of becoming lost. These factors become important to consider in certain areas such as those associated with high crime rates or areas with crowding (for example, certain travelers may wish to avoid tourist hotspots during navigation to a particular destination). Complementary combinations of various navigation methods are often the most useful in maintaining positive navigation experiences, as well as keeping us safe. In addition, a study related to this dissertation suggests that when an individual has a positive experience in terms of location accuracy with a navigation system, the individual's trust of the navigation system may increase (Wei & Bell, 2012). So once we have the positive navigation experience with any forms of UPS, we could obtain great benefits from those.

Advanced ubiquitous technology such as GPS can be a solution for supporting outdoor activities requiring navigation, however discretion must be maintained. Travel within a well-known environment does not necessitate GPS, as our personal spatial knowledge is likely more efficient. In addition, it is possible to navigate new environments without GPS through spatial knowledge gained indirectly through methods such as communication with others, web-based resources, or maps. Recall that the level of acquired spatial knowledge differs among individuals based on personal spatial abilities, (Golledge, 1999b) and that we are not only navigating in well-known or risk-free environments. Different navigation methods vary based on different situations, however GPS has the ability to support us in maintaining parallel navigation experiences across various new environments.

Sufficient spatial knowledge is a key to achieve successful navigation. Even if our navigation is supported by GPS, sufficient spatial knowledge will always tend to maximize our navigation experience. Recent trends in society are towards faster and more efficient lifestyles, some which is facilitated by GPS. Navigational support through GPS is not quite as flexible as our cognitive map and associated spatial knowledge, however GPS can help us maintain navigation performance and experiences among various environments where we have little or no familiarity. Two factors are essential in maximizing navigation experience: familiarity with our environments, and quality of our navigation strategy deployment. Familiarity with GPS does not need to be constitutively re-learned, as all basic GPS principles tend to be the same. This technology delivers our current location instantly to a handheld map. Assuming the relationship between a current location icon and a physical location and direction is understood, we will maintain parallel navigation experiences across various environments.

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CHAPTER 6

SYNTHESIS AND SUMMARY

Navigation is a central component of modern-day life. Never before has civilization relied upon navigation so frequently in as large scale as today. For this reason navigation is necessary to achieve the demands of daily life; without it, we face significant difficulty in attaining our needs. Noteworthy progress has been made in understanding the difficulties of human navigation in modern society (Chang, 2002; Claramunt, Parent, & Thériault, 1997; Hirtle & Hudson, 1991; Sun, Lin, & Li, 2012). Additionally, ubiquitous navigation systems have been introduced to overcome difficulties in numerous spatial activities; despite this, a satisfactory high-fidelity indoor navigation system has yet to be established (Borriello et al., 2005; Fallah, Apostolopoulos, Bekris, & Folmer, 2013; Hightower & Borriello, 2001; Li, Kam, Lui, & Dempster, 2007; Prasithsangaree, Krishnamurthy, & Chrysanthis, 2002). The necessity of an advanced indoor navigation system, which can reduce the navigation disparity between outdoor and indoor environments, has been increasingly examined.

While many mobile devices and location aware services have become popular navigation assistant applications, we can now easily assign an alternative navigation strategy other than our own for our daily spatial behaviour. Currently we are able to check our current location in both outdoor and indoor environments on many mobile devices, allowing us to save time in distinguishing our final destination from our current location. There is currently a lack of information about the ways in which such navigation tools impact human abilities in navigating and processing spatial knowledge (Jung & Bell, 2014). It is commonly hypothesized that frequent use of a navigation system compromises our abilities in attaining spatial knowledge while traveling (Münzer et al., 2012; Waters & Winter, 2011); as of yet, there is no cohesive explanation to verify this. If innovative navigation technologies can help us reach a series of destinations efficiently and reduce disorientation, we are more aware of how our navigation and spatial abilities interact with these technologies to maximize positive and minimizing negative impacts.

The technological advance of a ubiquitous navigation system allowing seamless support from outdoor to indoor environments will result in increased navigational safety and efficiency based on sensor defined dead-reckoning information and customized (system specific) geographic information. Additionally, the impact of navigation technology on our overall navigation ability can be examined. In this research, optimal methods are presented for building a universally available indoor navigation system with desirable system accuracy and consistency based on a review of the potential problems broadly investigated in actual indoor environments (Jung & Bell, 2013). Furthermore, we present how a ubiquitous navigation system can impact our navigational abilities and recommend ideal ways of using such a system among numerous navigational situations. In summary, this research demonstrates the way in which we can raise environmentally consistent navigation experiences based on developing and improving a ubiquitous navigation system for indoors. Additionally, we deliver a brief response to comprehensive questions regarding before and after use of such a system.

6.1 CONCLUSIONS

6.1.1 Quantitative Comparison of Indoor Positioning on Different Densities of WiFi Arrays in a Single Environment

Recent advances in location finding and mobile technology trigger increased demand for enriched geographic information in the palm of our hand. Global Positioning System (GPS), mobile, and other radio technologies allow us to obtain real-time location and geographic information (Bell et al., 2010; Steiniger, Neun, & Edwardes, 2006); however, when GPS becomes unreliable, real-time location information can become misleading due to its positioning error (Hightower & Borriello, 2001). Fortunately, interrupted GPS signals could be fixed through the use of other additional sensors or hardware in outdoor environments (Huang, Tsai, & Huang, 2012; Li, Tan, & Dempster, 2010; Mok, Retscher, & Chen, 2012). In addition, a novel positioning approach is required indoors as these environments pose a particular challenge due to the degradation or hindering of the GPS-signal as it penetrates building structures. In order to overcome some of the challenges associated with indoor navigation, a WiFi-based Positioning System (WPS) called the Saskatchewan Enhanced Positioning Systems (SaskEPS) has been developed (Bell et al., 2010). SaskEPS is designed to provide seamless navigation service from outdoor to indoor environments, and is associated with GPS.

SaskEPS presents a robust WiFi-based indoor positioning system that could be integrated with GPS as a universal indoor navigation system (Jung et al., 2012). SaskEPS's trilateration algorithm and information-rich database can sustain reliable positioning services in many indoor environments. One of the predominant benefits of using a rich database is that once developed from a "bottom-up" approach, it becomes manageable with reasonable maintenance. In addition, the trilateration algorithm works well even if WiFi signals are shifted due to the absence of WiFi signals or WiFi-Received Signal Strength Index (RSSI) alteration. SaskEPS is able to provide a 2.5 dimensional positioning result (horizontal location with floor information) with minor positioning error, however a certain number of WiFi-routers should be kept in order to satisfy the minimum environmental requirement for producing indoor positioning services with minor positioning error (Jung et al., 2012). Universal IPSs similar to SaskEPS would greatly increase opportunities for both visitors and regular users to access secure and reliable indoor positioning for most of their indoor activities where the majority of their routine activities take place. Universal IPSs would increase the efficiency of a ubiquitous positioning system, augment the convenience of wayfinding, and allow for more effective navigation with reduced spatial anxiety without environmental inconsistency.

6.1.2 Potential Risks of WiFi-based Indoor Positioning and Progress on Improving Localization Functionality

Many WiFi-based indoor navigation systems are currently available. Examples include Google's Android™ and Apple's iOS™; with these, we can instantly access indoor positioning services through our mobile devices. Commercial WiFi-based indoor positioning systems are continuously improving, however their indoor positioning service quality is very inconsistent among different environments, or yet comparable with GPS (Jung & Bell, 2013). It should be noted that a number of very accurate indoor positioning systems have been developed that are unsuitable for universal deployment due to strict requirements for special sensors or equipment, limited area usability, and highly labor-intensive systems (Manodham, Loyola, & Miki, 2008; Papagiannakis, Singh, & Magnenat-Thalmann, 2008; Torres-Solis, Falk, & Chau, 2010). In contrast, WiFi is commonly available in many indoor environments, with WiFi connection capabilities for most mobile devices. If we can use WiFi signals in an alternative manner, we can add new value to pre-existing WiFi networks. For this reason, WiFi has been chosen as a cost-efficient source for many IPSs (Bell et al., 2010).

Hypothetically, WPSs could provide indoor positioning as a complementary source for many GPS-based systems for outdoor environments. WPSs could be easily deployed where enough WiFi routers exist; however potential signal and environmental (structural) interruptions should be carefully assessed in order to reduce the level of positioning error (Jung et al., 2012). This study presents some suggestions that could minimize the level of positioning error present in such systems. Once potential interruptions are removed or condensed, WPSs including SaskEPS close to be a universal indoor positioning system supplemental to existing GPS and others

GPS uses a trilateration algorithm for its location determination process. Many innovative approaches and techniques have been introduced for the improvement of GPS's positioning quality; these are not only improving GPS's positioning accuracy but also improving its results based on associations with certain spatial characteristic in the surrounding environment (Jung et al., 2012; Thiagarajan et al., 2009). For example, most vehicle GPS systems use a map-matching method for preventing high levels of positioning error, as a vehicle under operation is typically staying on road segments during travel (Taylor & Blewitt, 1999). SaskEPS produces similar location information indoors, like GPS outdoors, so a map-matching method could be applied to SaskEPS for enhancing its positioning quality and visual cognition. When an indoor pedestrian is in locomotion, their possible location can be limited in the hallways where a pedestrian can be or is allowed to be (Zhang, Wang, & Wan, 2003). When walkable indoor physical space is converted into a Walkable CentreLINE (WCN) and a map-matching method is applied to SaskEPS, WCN becomes the meaningful footpath for an indoor pedestrian who is in locomotion. This WCN and map-matching technique improves SaskEPS's positioning quality in terms of accuracy and human perception of current location; to further augment SaskEPS's position results, a spatiotemporal geographic concept which associates the recent chronological location (most recent dead-reckoning information) could be utilized. In general, if WPSs can be incorporated with WCN and a map-matching technique, WPS can be one step closer to becoming a trustworthy indoor positioning system, analogous to GPS outdoors. WPS could improve the efficiency of our daily navigation, increase convenience in accessing necessary resources, and provide new opportunity in reaching various destinations more securely (Jung et al., 2012).

6.1.3 Modifications in Human Navigation Performance and Patterns Based on the Availability of GPS-Based Navigation System

An important consideration for successful navigation is how humans acquire adequate spatial knowledge and do so efficiently. In modern society, individuals frequently need to navigate to new destinations where our spatial knowledge is incomplete, or absent altogether. Individuals require enough spatial knowledge to enable us to reach a destination. When our spatial knowledge is incomplete, we may become partially lost or end up traveling with high anxiety. On the other hand, if we have more knowledge about a new destination based on our experience, spatial knowledge becomes more complete and we are able to navigate with increased confidence (Golledge, 1999a). In recent times, navigation has been easily supported through the use of ubiquitous navigation systems. Because of this, we rarely have to worry much about how we reach a destination. Many navigation systems deliver necessary geographic information and current locations with machine tracked dead-reckoning information.

Research has addressed that long-term use (cumulated experience) of GPS and how it could affect the navigation experience with new habits associated with reliance on, or availability of, navigation technology (Axon, Speake, & Crawford, 2012; Speake & Axon, 2012). Certain factors shift our spatial behaviour in light of dependence on GPS for navigation. GPS may or may not be available to us or could become unavailable in the former circumstance. Individual navigation experiences should be viewed closely for identifying how our interactions with the availability of GPS affect navigation behaviours for each micro-case that may occur with our daily use of GPS. In addition, when GPS becomes unreliable, our trust in the positioning system can be reduced (Wei & Bell, 2012). Further examination of the factors that damage our trust in such a system should be undertaken.

Our daily lives require us to constantly make decisions, as the decision-making process establishes the connections between one situation and another; therefore decisions are a part of both recurring and new situations. More advanced navigation systems will become available to support navigation ubiquitously but the impacts of whether or not and how frequently we expose ourselves to such systems are worth considering. If we decide to use such support, we should consider under what circumstance the use may occur and how to most benefit from the system. This research provides suggestions towards some of the concerns we must consider while using GPS, including situations where GPS availability is either unstable or inconsistent. Additionally, we highlight how our navigation is affected through the use of these positioning systems, and consider the advantages of navigating both actively and passively.

Both active (non-machine lead dead reckoning) and passive (machine lead dead reckoning) navigation modes have the potential to benefit our daily navigation experiences. Individuals can accomplish both successful and efficient navigation without GPS, however if they make even a small number of mistakes or wrong decisions during travel, their overall navigation experience could be inefficient and result in increased anxiety. For preventing negative navigation experiences, participants need to a) familiarize themselves with their surroundings before traveling in any novel environments, or b) utilize GPS technology for support. GPS assistance may enable people to save time, and although it may not assure opportune navigation performance, it is capable of reducing disorientation and unnecessary travel costs such as continually seeking correct directions. Acquiring an abundance of spatial knowledge is a prime key in assuring positive navigation experiences for both active and passive modes of navigation. Although individuals' navigation may be supported by GPS, adequate spatial knowledge will promise a more comfortable navigation experience. Artificial navigation through GPS tends to be inflexible when taking place of our personal cognitive maps and associated spatial knowledge. Despite this, GPS could allow us to have parallel navigation experiences in different environments in which we have little or no familiarity and in different individuals who have a different level of spatial knowledge on specific location. When our navigation is fully dependent on GPS, familiarity with the positioning system is a critical factor. In contrast, if our navigation begins in active mode before being converted to passive mode, GPS familiarity is no longer critical for effective navigation. For this reason, our active navigation experience allows us to maintain high spatial familiarity, so later use of a GPS system is only required for confirmation of whether or not an individual is headed in the correct direction.

We may not require GPS for navigation, as historically humans have navigated successfully without positioning systems and other spatial tools. Lack of current navigational technologies would result in varied navigation experiences based on individual levels of spatial knowledge. A question that may be considered is that given the availability of tools for reducing navigation uncertainty, perhaps the use of such tools should be restricted as we have survived without them for so many years previously. GPS may not be fully necessary, but it does result in certain disadvantages when not using GPS as a backup plan for our daily navigation, especially when our spatial knowledge is reduced, when we wish to suddenly travel to a new place, or in situations of unexpected disorientation with our surroundings.

6.2 DISCUSSION

Research on human navigation is directly beneficial to us, due to the intrinsic relationship between humans and the phenomenon of navigation. It is important to consider navigation in both indoor and outdoor environments as we are required to maintain decent navigation experiences for sustaining our quality of life in both types of environments. Previously, this paper discussed the usability of indoor navigation systems and how GPS-like indoor navigation systems can be designed and implemented. When universal indoor positioning systems become available, a universal indoor system is expected to rapidly gain in popularity, much like GPS. Many researchers have studied the differences between indoor and outdoor environments and how people navigate both. We may yet need to understand how our perception changes when moving from outdoor to indoor environments or vice versa until we are using a complete UPS, universally enabled in outdoor and indoor environments. Furthermore, if a completed UPS is selectively available based on the environment, how are our navigational behaviours affected? Our society is changing more rapidly than ever, with numerous new technologies being continuously introduced to us. New technologies often provide us with new opportunities; however we need to consider the impact these have on society, what their true benefits are, and how we can maintain autonomy before fully adopting them.

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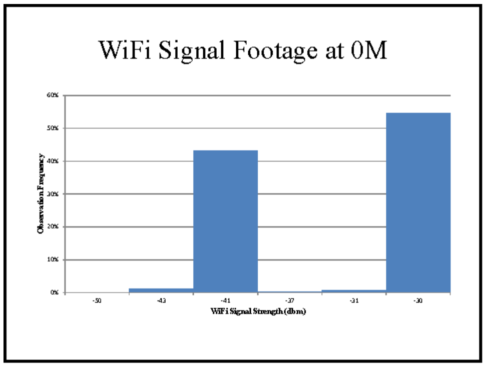
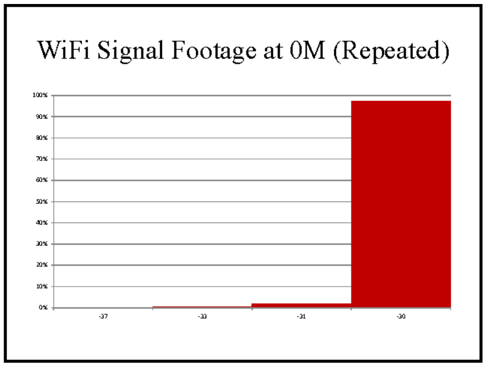
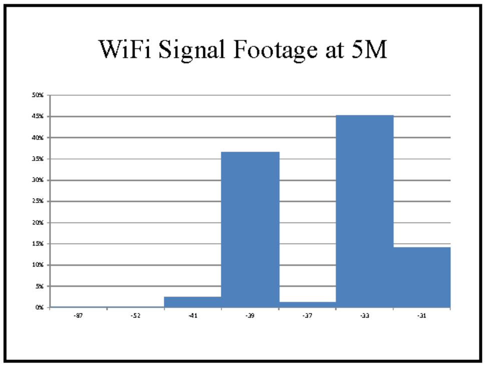
APPENDIX A

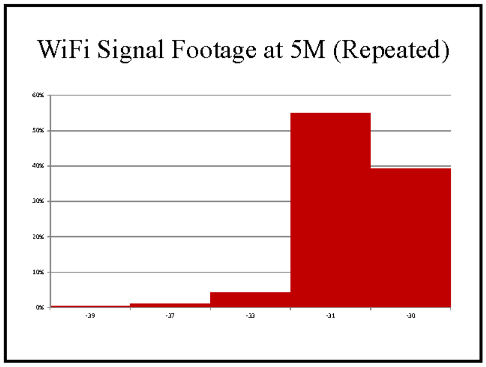
Characteristic of Three Different Routers' WiFi Signal Footage

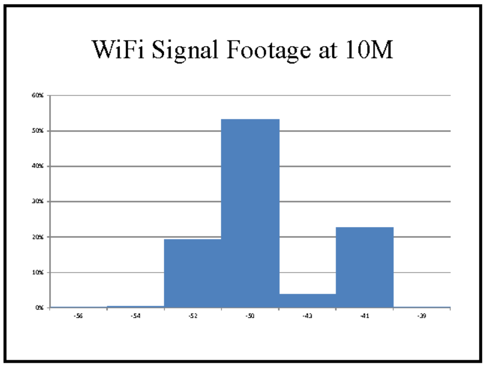
1. WiFi Signal Footage – Router A

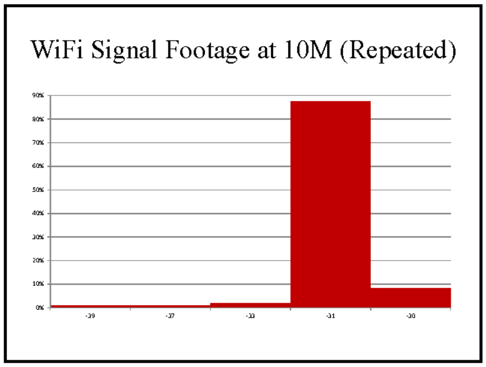


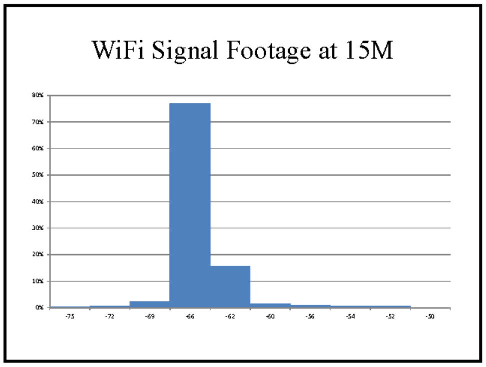


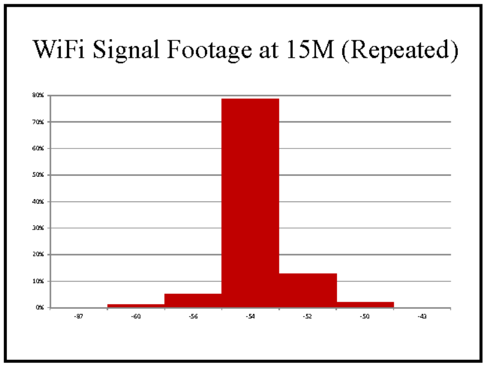




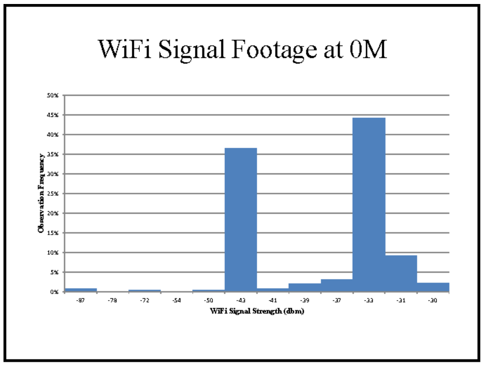


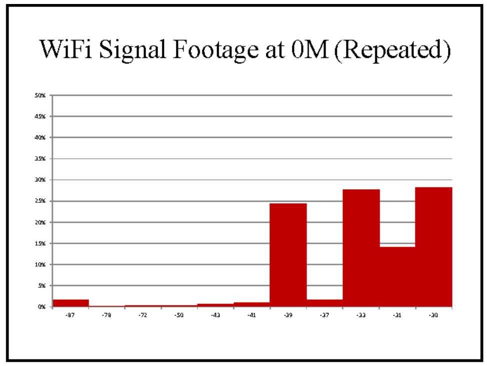


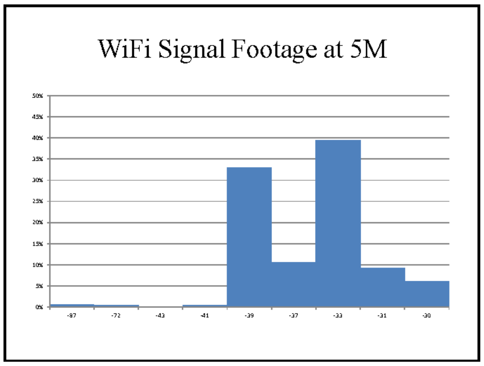


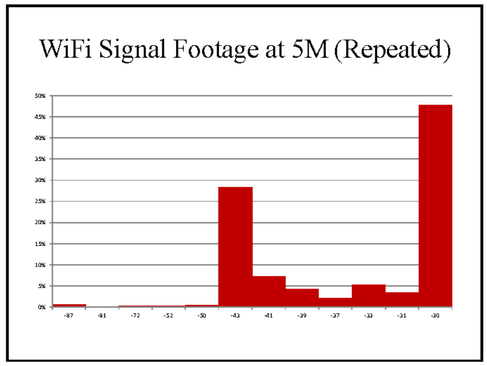


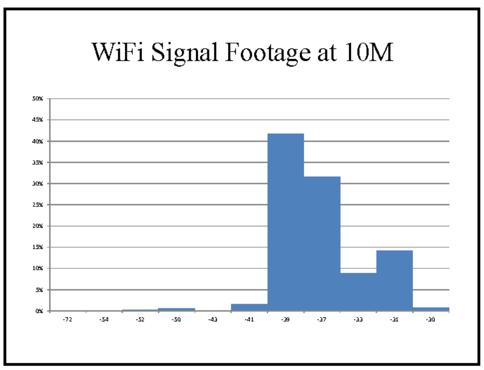
2. WiFi Signal Footage – Router B

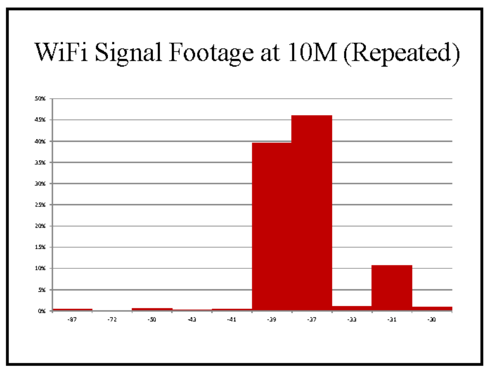


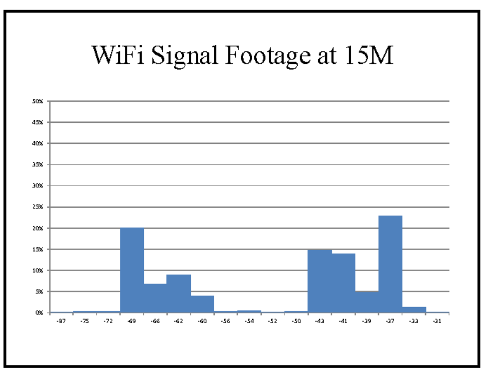


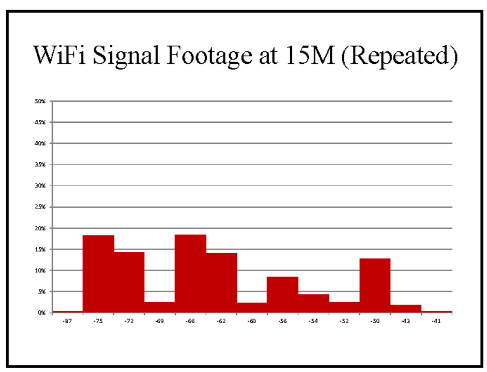




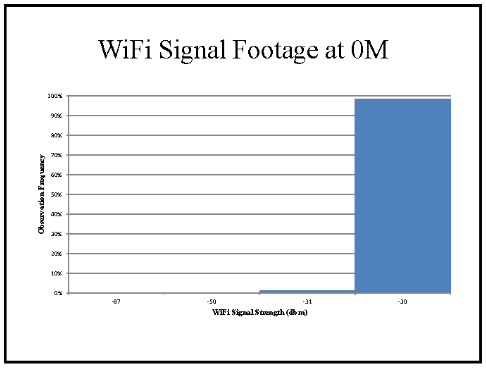


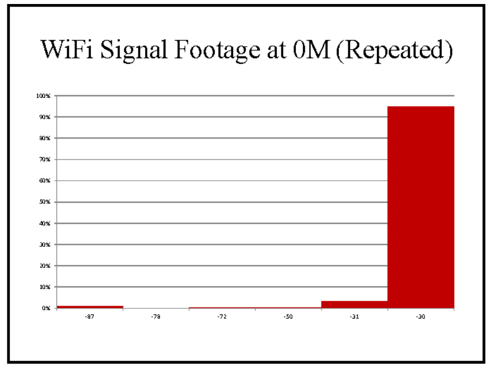


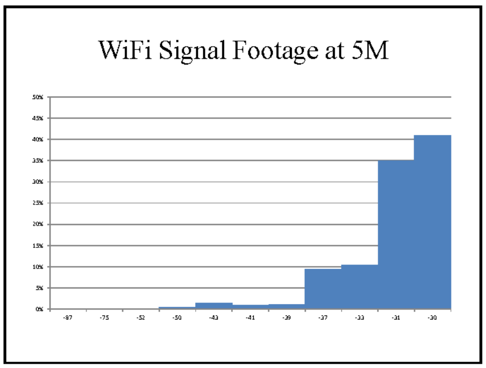


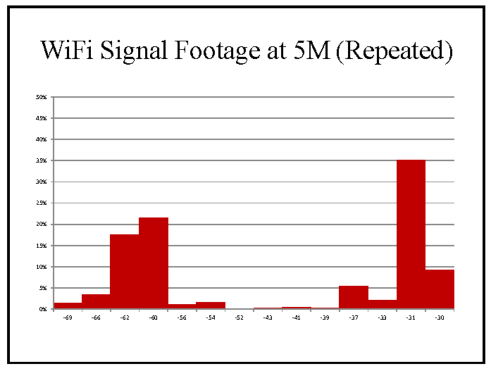


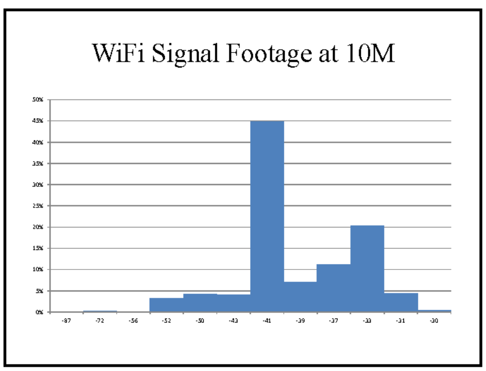
3. WiFi Signal Footage – Router C

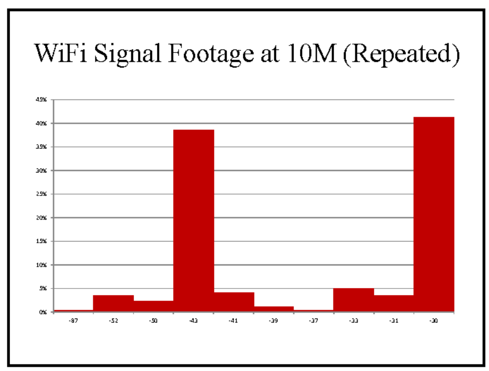


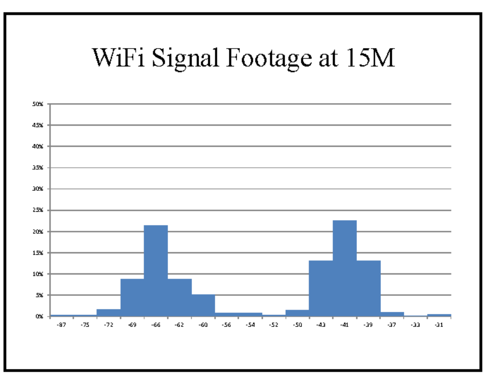


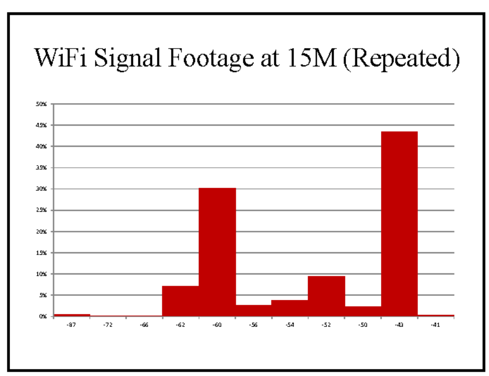












APPENDIX B
An Experiment Script of Chapter 4

Materials

Experimenter: Stopwatch
iPad
Additional GPS device
White campus map
Scratch paper (to record participants' behaviour)

Participant: GPS device (To track travel route)
If applicable, additional GPS devices for navigational support

Phase 1: Indoors

10 – 15 Minutes

Meet participant at location decided upon by experimenter and participant beforehand. Using the following script, welcome the participant and introduce him/her to the basics of the experiment.

"Hello, thank you for coming. Please have a seat and set your cellphone to silent. This study is designed to analyze the impact of positioning technology on human navigation. Your participation will involve three parts. First, you will be doing one questionnaire and three surveys with the iPad. Second, we will go outside for the navigation experiment and pointing tasks. The final part will involve your completion of some post-experiment questionnaires. Each part should take 20 minutes, more or less – everyone is a little different. Before we start, please take the iPad in front of you and read the consent form. You may end your participation at any time during the experiment, and any data provided by you will be permanently deleted. All of the data I collect is kept anonymous.

When you are ready to begin, please let me know."
Wait for participant to read and sign the consent form provided.

"Please start by answering the pre-experimental questionnaire. Once you finish the survey, you can begin the first part of the experiment using the iPad. Please read and follow the instructions carefully. If you have any questions regarding the survey, or wish to have any additional instructions, please don't hesitate to let me know."

Phase 2: Outdoors

25 – 30 Minutes

Wait for the participant to indicate his/her completion of the iPad questionnaire and all three iPad surveys.

"We are now going to start the second part of the experiment. Before we head outside, I would like you to take five minutes to familiarize yourself with the experimental route, using this map. Please read it carefully."

Wait five minutes and politely stop participant.

"We will now go outside, so please wear your coat and gloves. You will also be wearing a GPS unit mounted on a bag that will record your locomotion. There are some cautions for this section of experiment that I would like you to be aware of. I will follow you for your safety, however, I will not provide any help or support for your navigation. If you do feel as though you are completely lost, you may ask me simple questions to aid in your understanding of where you are. I will give you a brief answer, but will be unable to navigate for you. I would like you to please follow the pedestrian path at all times and for you to not answer your cellphone or stop for friends while you are navigating. Please keep in mind that you may end your participation at any time and for any reason during the experiment."

"If you wish to leave your things here, please feel free as the office will be locked for the duration of the experiment."

Walk with participant to starting point for the experiment. There are three situations for this part of the experiment, one involving an additional GPS device for both routes, another not involving any other GPS devices for both routes, and a third situation involving use of an additional GPS device for the first route, but not for the second.

Situation 1 (Additional GPS device)

Offer the additional GPS device to the participant and accompany him/her as they navigate to the final destination of the first route. Congratulate him/her upon their arrival and suggest a short break at the USSU lounge before resuming the experiment. Make sure to reclaim the additional GPS unit for the duration of the break, but return it to the participant for the second navigation task. As before, accompany participant and congratulate them upon their arrival at the second destination.

Situation 2 (No additional GPS device for either route)

Direct participant to begin their navigation. Accompany participant for the duration of their route. Once participant has arrived at the final destination, congratulate him/her and suggest a short break at the USSU lounge before resuming the experiment. After the break, again direct participant to begin their navigation, and as before accompany them to the final destination.

<u>Situation 3 (Additional GPS device for one route, no GPS device for second route)</u>

Offer the additional GPS device to the participant and accompany him/her as they navigate to the final destination of the first route. Congratulate him/her upon their arrival and suggest a short break at the USSU lounge before resuming the experiment. Reclaim the additional GPS unit. After the break, direct participant to begin their navigation of the second route, but do not offer them the additional GPS device. As before, accompany him/her to the final destination. Note that the participant may use the additional GPS device for the second route, not the first, in which case do not offer the participant the additional GPS unit until after the break.

Following any of the three situations, a pointing task must be completed before heading back to the location of the first phase of the experiment. Direct participant to complete the pointing task. Thank participant and accompany him/her back to the office

Phase 3: Indoors

10 – 15 Minutes

Arrive with participant back at the initial location of the experiment, and use the following script to finish the experimental procedure.

"We will now begin the final part of the experiment. There is a post-experimental questionnaire for you to complete, with scratch paper provided. Please read the instructions carefully, and if you have any questions, please let me know."

Wait for participant to indicate completion of the questionnaire.

"This is the end of the study. Your participation has been much appreciated. If you have any questions, or would like to know more about the purpose of this study, feel free to let me know. Thank you!"

APPENDIX C

Pre and Post Surveys and a Sketch Map Task of Chapter 4

1. Pre-Survey

Surery before performing positionging task

Participant ID: _____________ Age: ______ Major: _____________
Gender: M F School Year: 1st 2nd 3rd 4th Grad

1. How familiar are you with the University campus in general? Please choose a number to rate your familiarity (1= very unfamiliar, 5= very familiar).

1 2 3 4 5

2. How familiar are you with the University campus, near the Engineering Building? Please choose a number to rate your familiarity (1= very unfamiliar, 5= very familiar).

1 2 3 4 5

3. Please rate your sense of direction? Please write down a number between 1 and 100 to rate your sense of direction (1= poor, 100= excellent).

4.. Do you often get disoriented when you are in a novel place?

A. Yes B. No

5.. Have you ever used a GPS-based navigation system to reach or find a destination?

A. Yes B. No

If yes, how often are you using such a system? (1=ocasionally, 5=very often)

1 2 3 4 5

If yes, have any problem while you are using a navigation system (1=never, 5=very often)

1 2 3 4 5

7. Do you own a smartphone or a tablet?

A. Yes B. No

2. Post-Survey

Surery after performing positionging task

Participant ID: ______________

1. How confident are you in the accuracy of your navigation during the experiment?
(1=no confident, 5=very confident)

1 2 3 4 5

2. How confident are you in the accuracy of your navigation without GPS (if applicable)?
(1=no confident, 5=very confident)

1 2 3 4 5

3. How confident are you in the accuracy of your navigation with GPS (if applicable)?
(1=no confident, 5=very confident)

1 2 3 4 5

4. Did you find the GPS-based navigation system helpful during your navigation (if applicable)?
(1=not at all, 5=very much)

1 2 3 4 5

5. Can you rate your navigation performance during the experiment?
(1=very poor, 5=very well)

1 2 3 4 5

6. Do you think you knowledge of campus (along the experimental route) has been improved?
(1=not at all, 5=very much)

1 2 3 4 5

8.Can you guess how long your experimental routes was (in Metres)?

First Route: Second Route:

3. A Sketch Map Task

Participant ID:

Draw a line on the given "map" that indicates the route you followed.

APPENDIX D

Pointing Tasks' Graphical Result of Chapter 4

1. Detail of Pointing Targets

   a. Lists of pointing targets

Building	Path	Pointing Target Description	Distance to Target (meter)	Angle to Target (degree)
Administration Building	2	Point to the Front Main Entrance of the Administration Building	210.83	185.10
Agriculture	1	Point to the Agriculture Main Entrance (South Side)	71.43	46.24
Archaeology Building	2	Point to the Entrance to Skywalk from Engineering to Archaeology	117.45	94.83
Athabasca Hall	2	Point to the South Side Entrance of Athabasca Hall (Near Faculty Club)	281.74	199.02
Biology Building	1	Point to the Entrance to Skywalk from Biology to Agriculture	121.28	270.47
Engineering Building	2	Point to the Entrance to Skywalk from Engineering to Agriculture	116.70	84.07
Faculty Club	2	Point to the Faculty Club	314.95	200.70
Kirk Hall 1	1&2	Point to the Kirk Hall Main Entrance	28.30	355.89
Kirk Hall 2	1	Point to the Entrance to Kirk Hall from Agriculture	68.48	17.60
Marquis Hall	1	Point to the University Bookstore	253.10	240.74
MUB	1&2	Point to the Memorial Union Building Main Entrance (Louis)	319.80	219.56
PAC	2	Point to the Middle of the PAC Front Main Entrance	291.31	172.96
Place Riel	1	Point to the Front Entrance of Place Riel (Bus Loop Entrance)	347.15	237.54
Saskatchewan Hall	1	Point to the Hospitality Service Entrance in the Saskatchewan Hall	275.51	214.59
Thorvaldson Building	1	Point to the Entrance to Skywalk from Geology to Thorvaldson	194.25	260.52

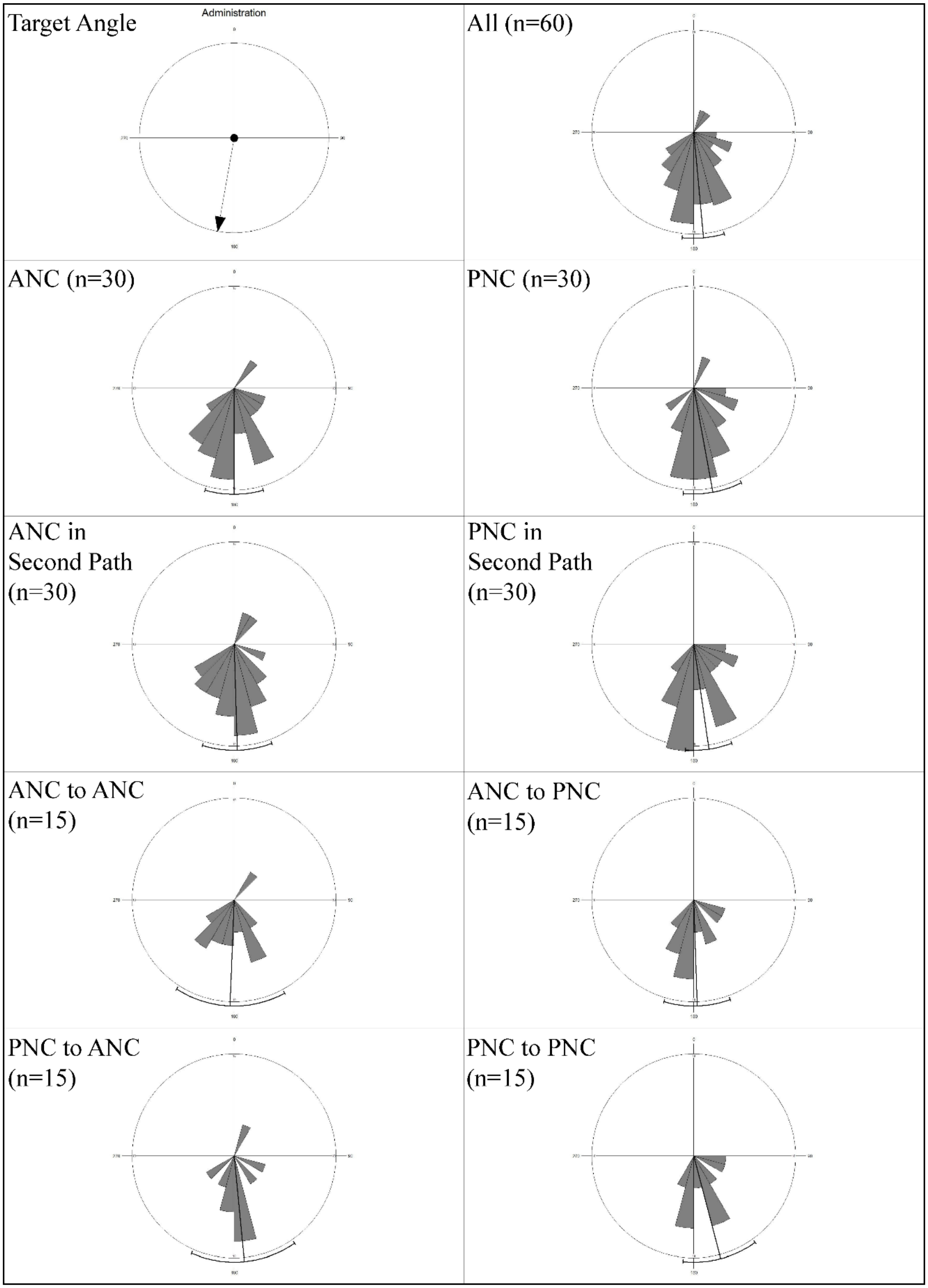
   b. Abbreviation detail

      i. Target Angle: Target direction from the participants' location

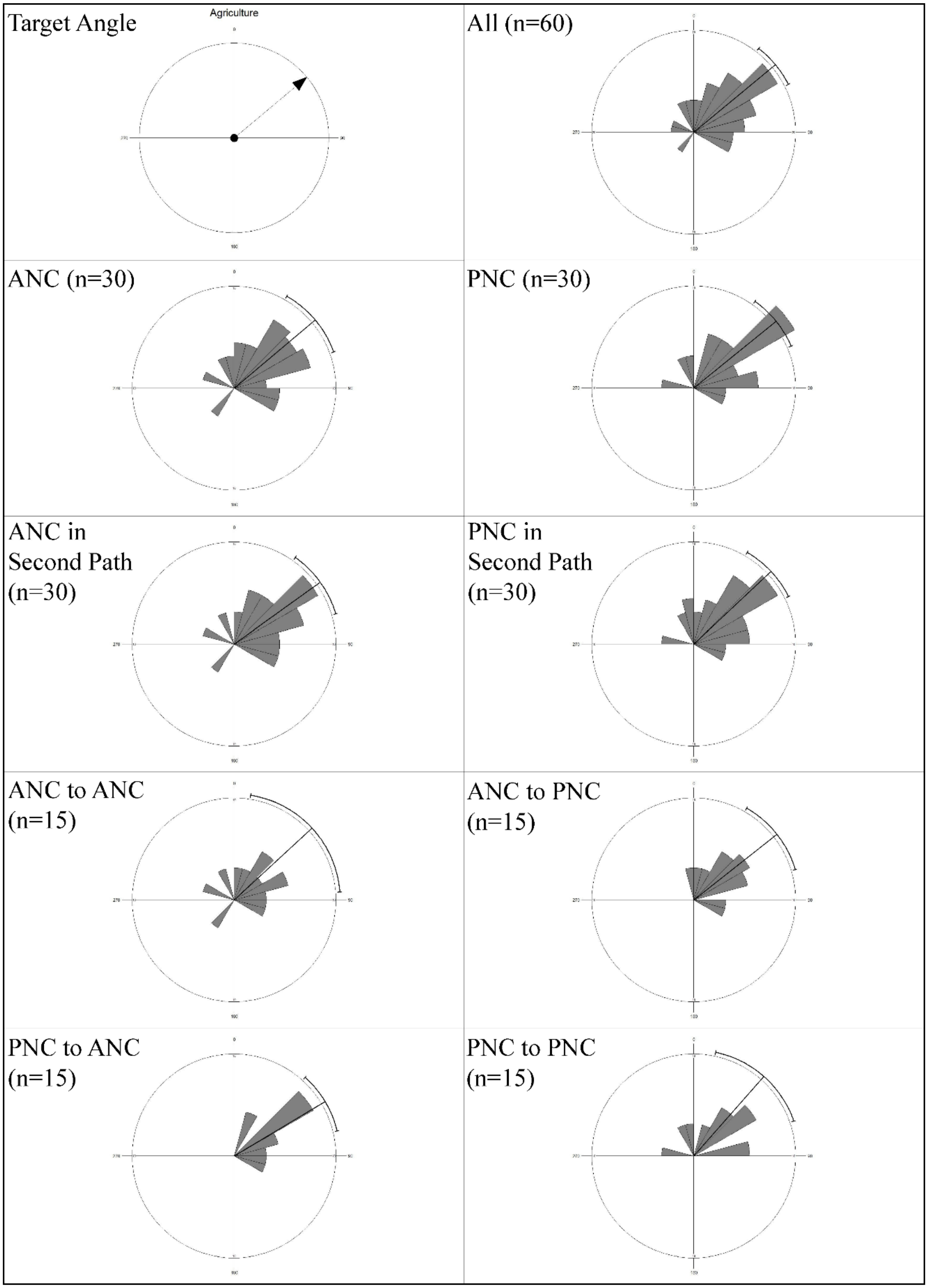
      ii. ANC (Active Navigation Condition): Navigation task without GPS

      iii. PNC (Passive Navigation Condition): Navigation task with GPS

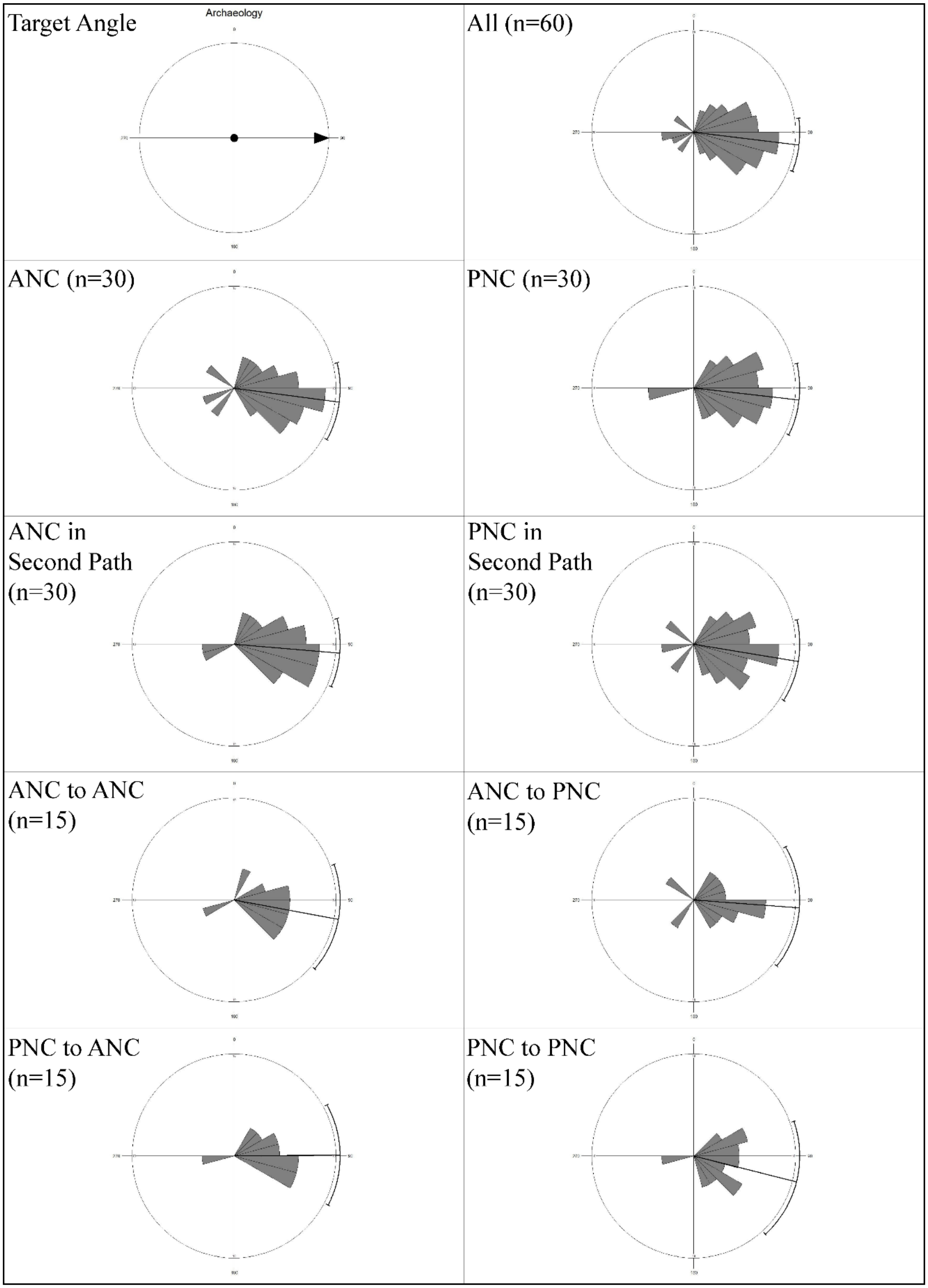
2. Administration Building



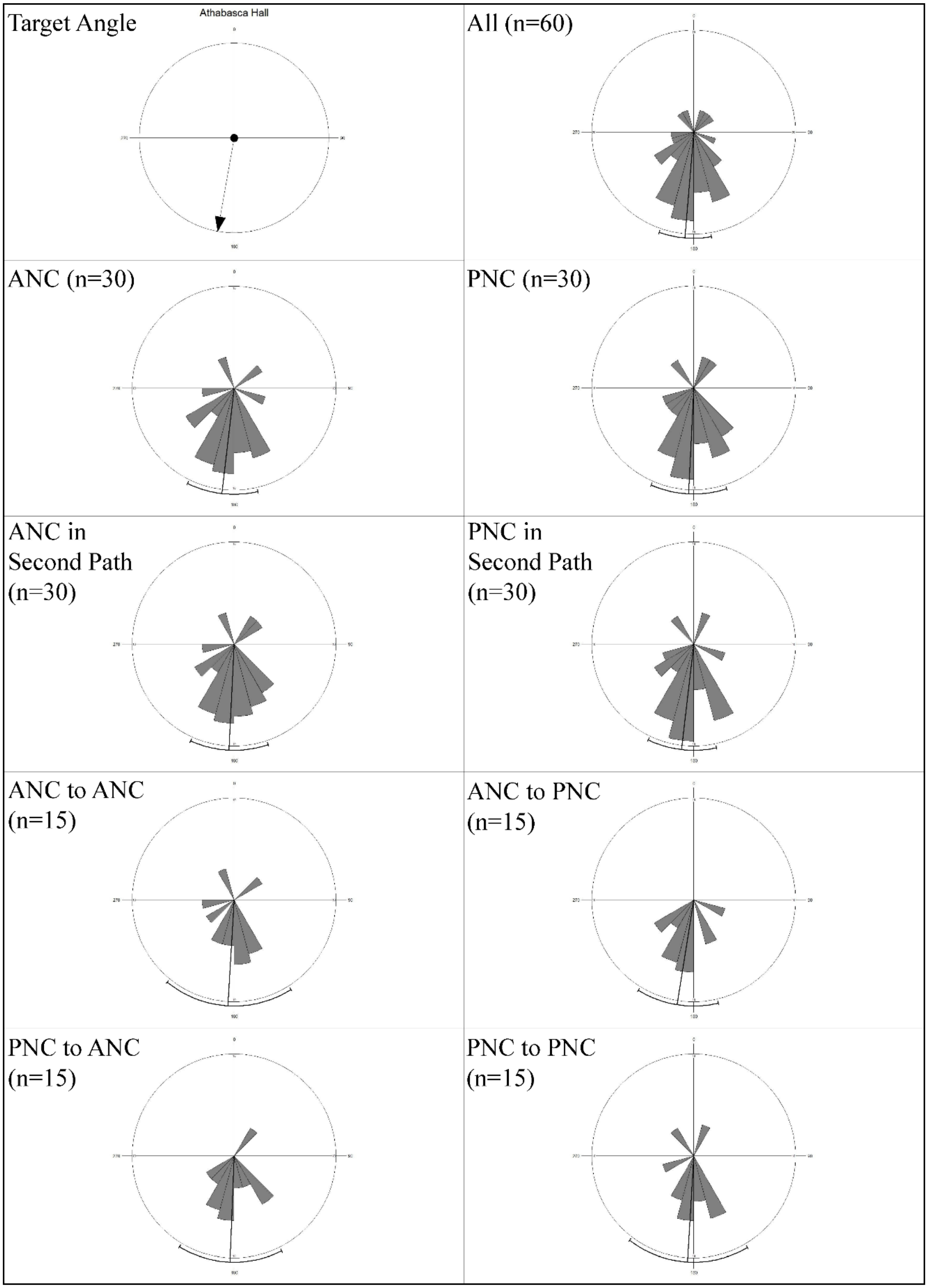
3. Agriculture Building



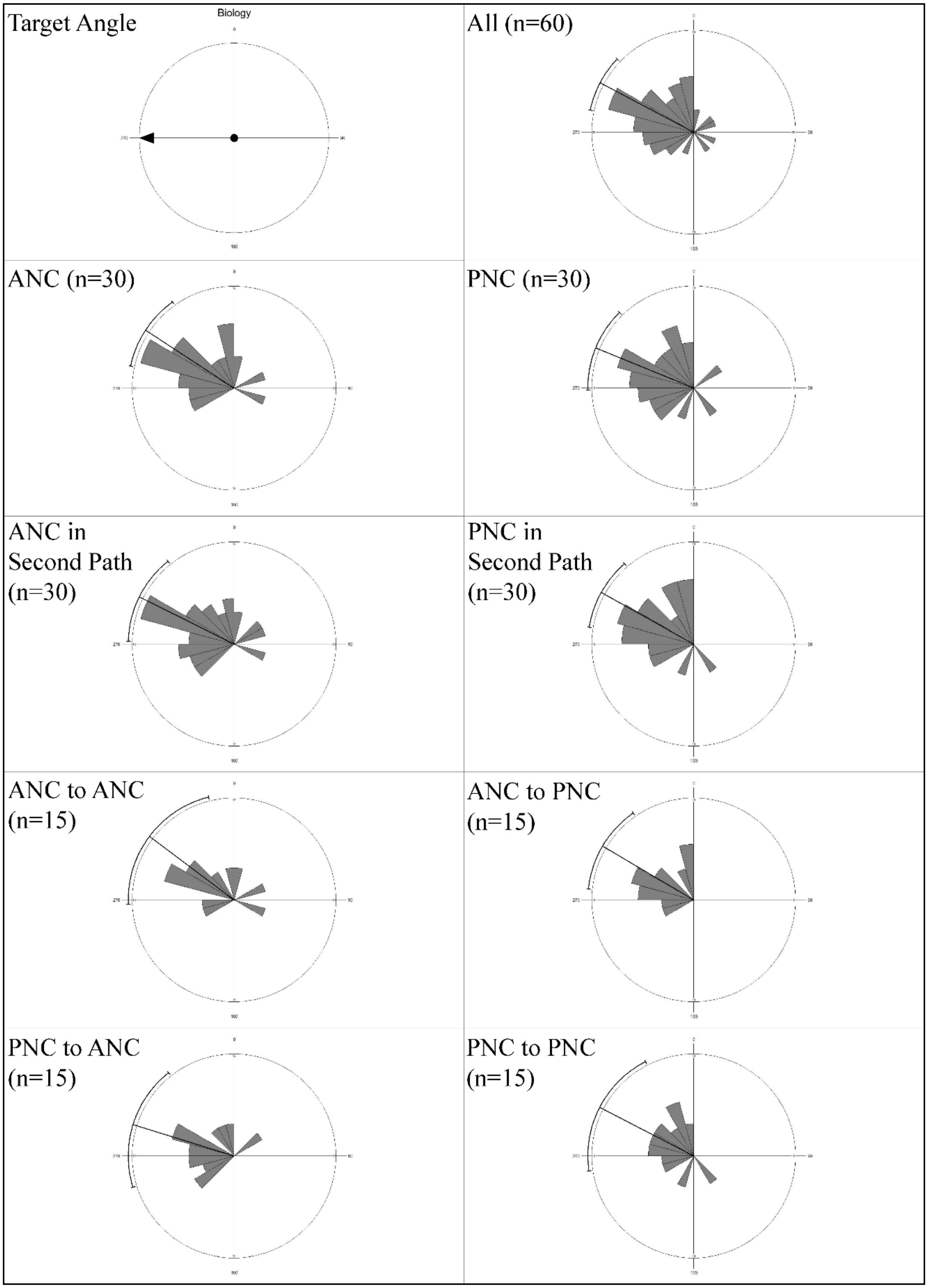
4. Archaeology Building



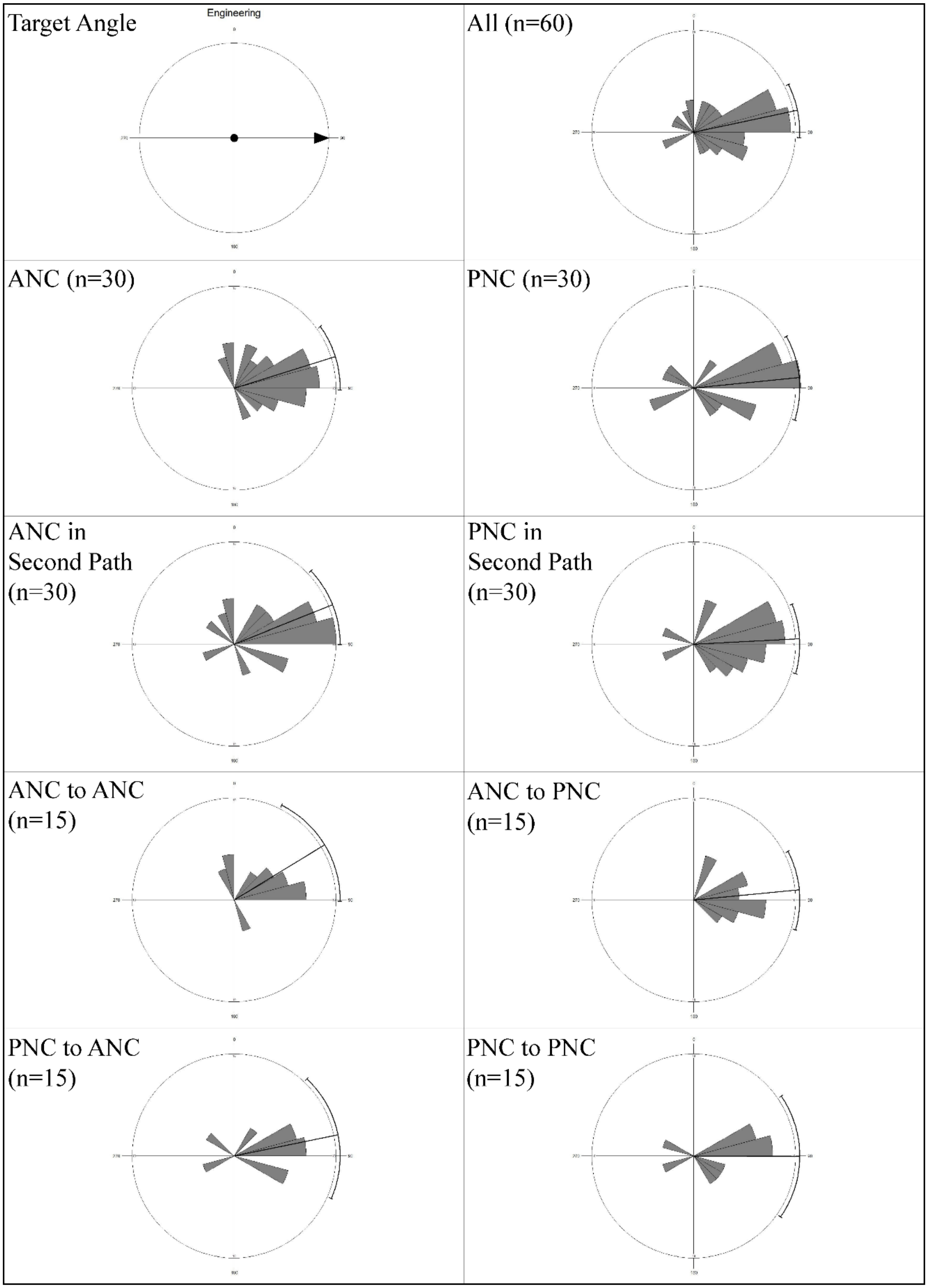
5. Athabasca Hall



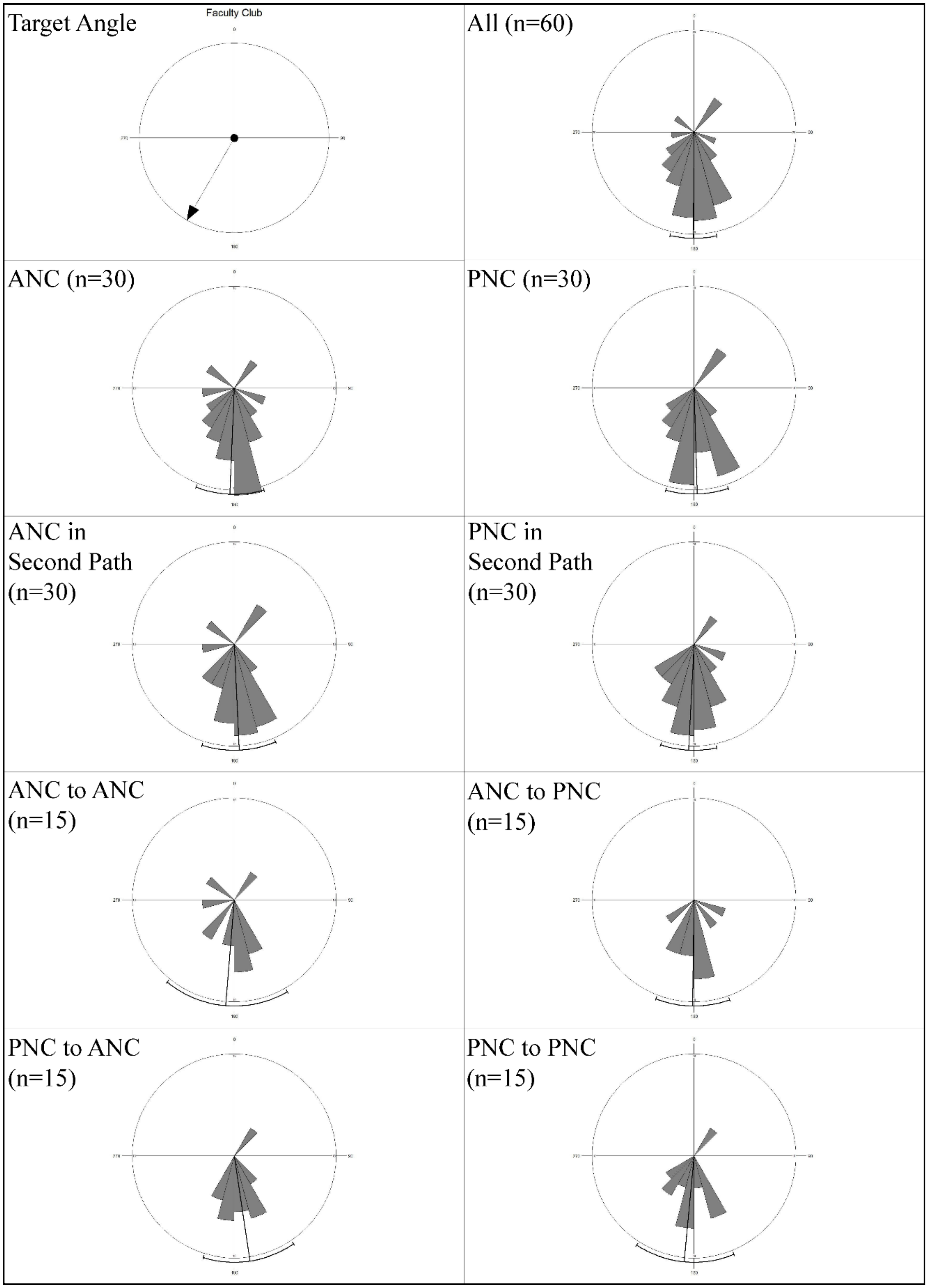
6. Biology Building



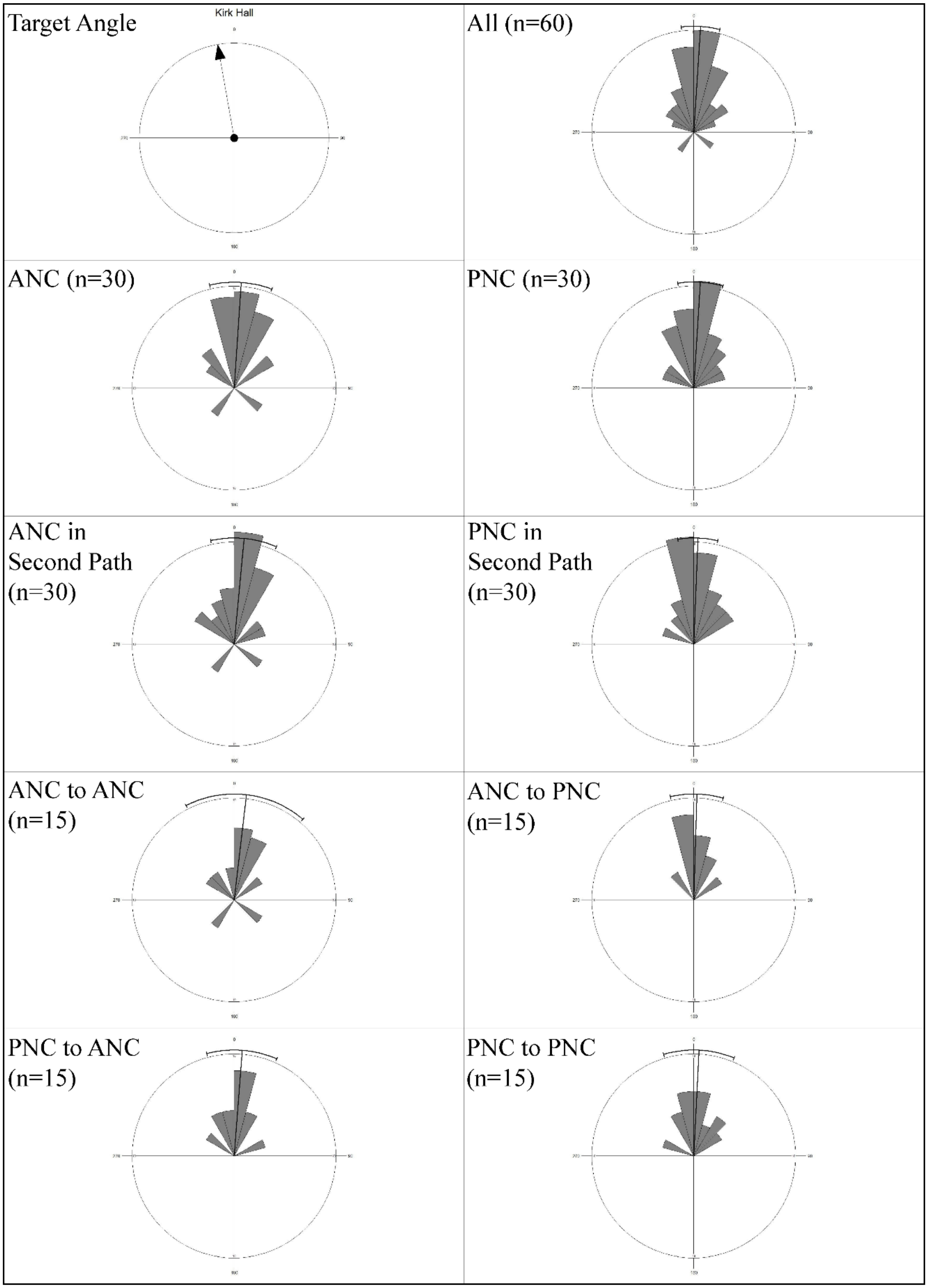
7. Engineering Building



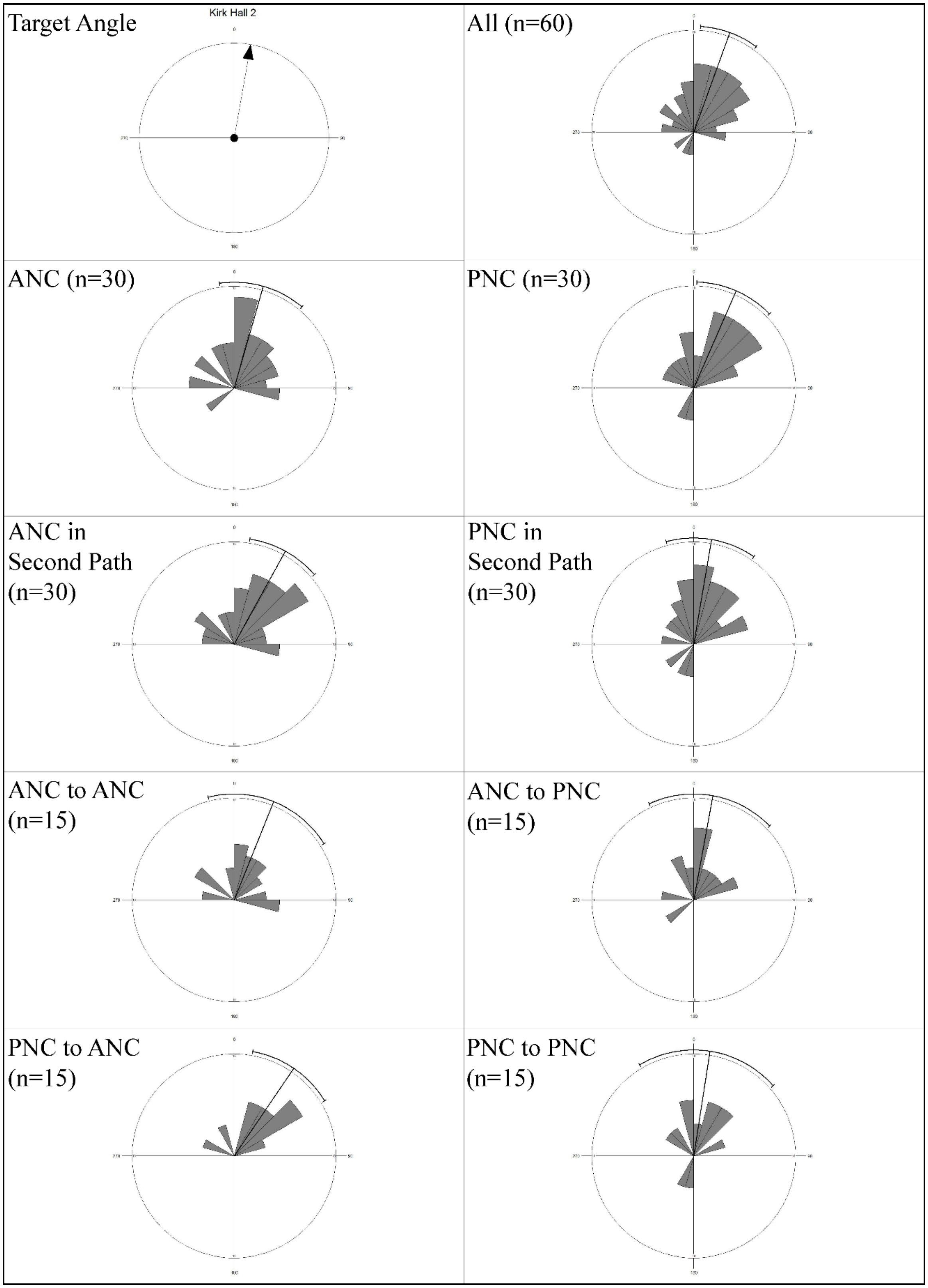
8. Faculty Club



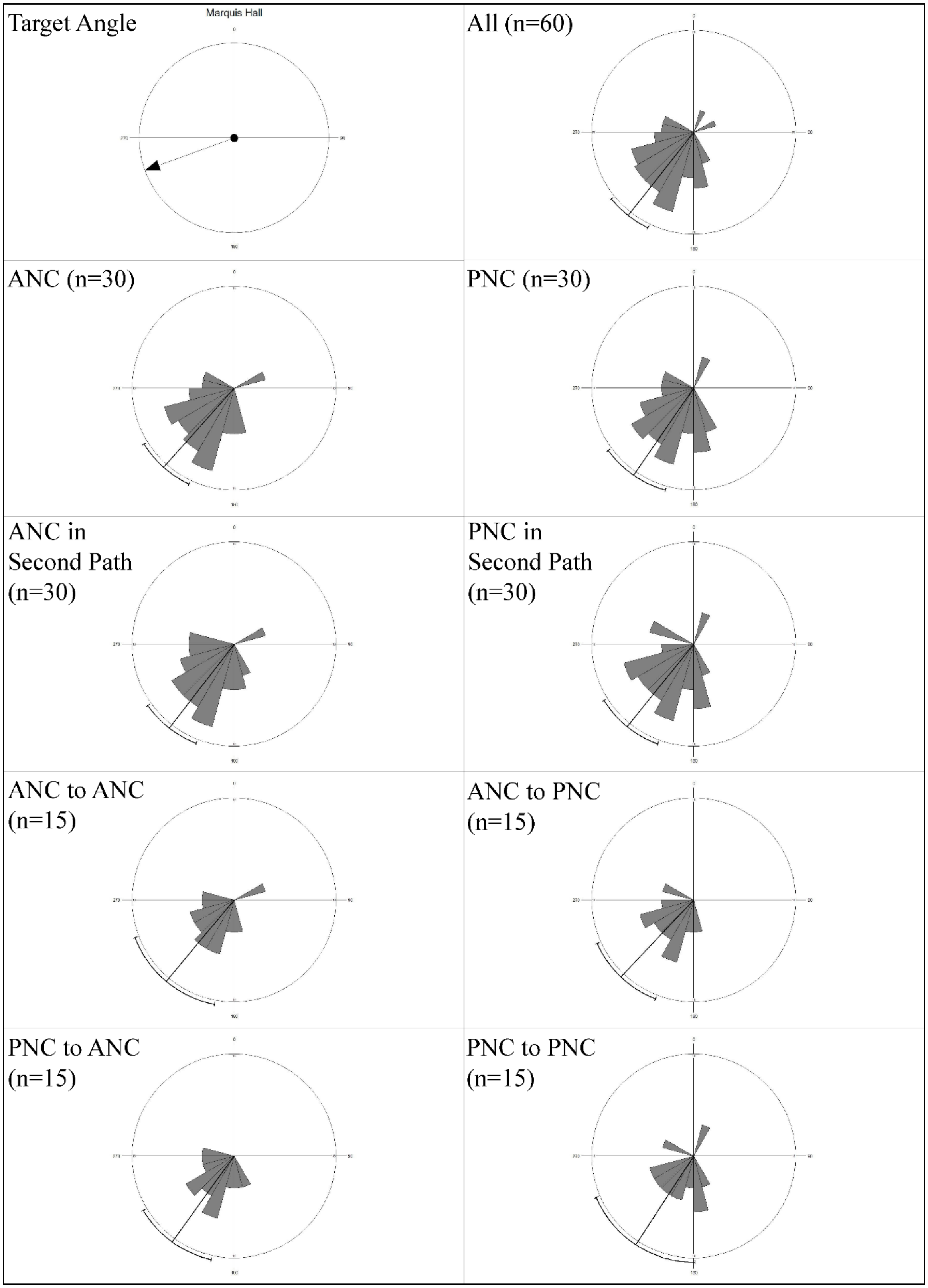
9. Kirk Hal 1


Target Angle
Kirk Hall
All (n=60)
ANC (n=30)
PNC (n=30)
ANC in Second Path (n=30)
PNC in Second Path (n=30)
ANC to ANC (n=15)
ANC to PNC (n=15)
PNC to ANC (n=15)
PNC to PNC (n=15)

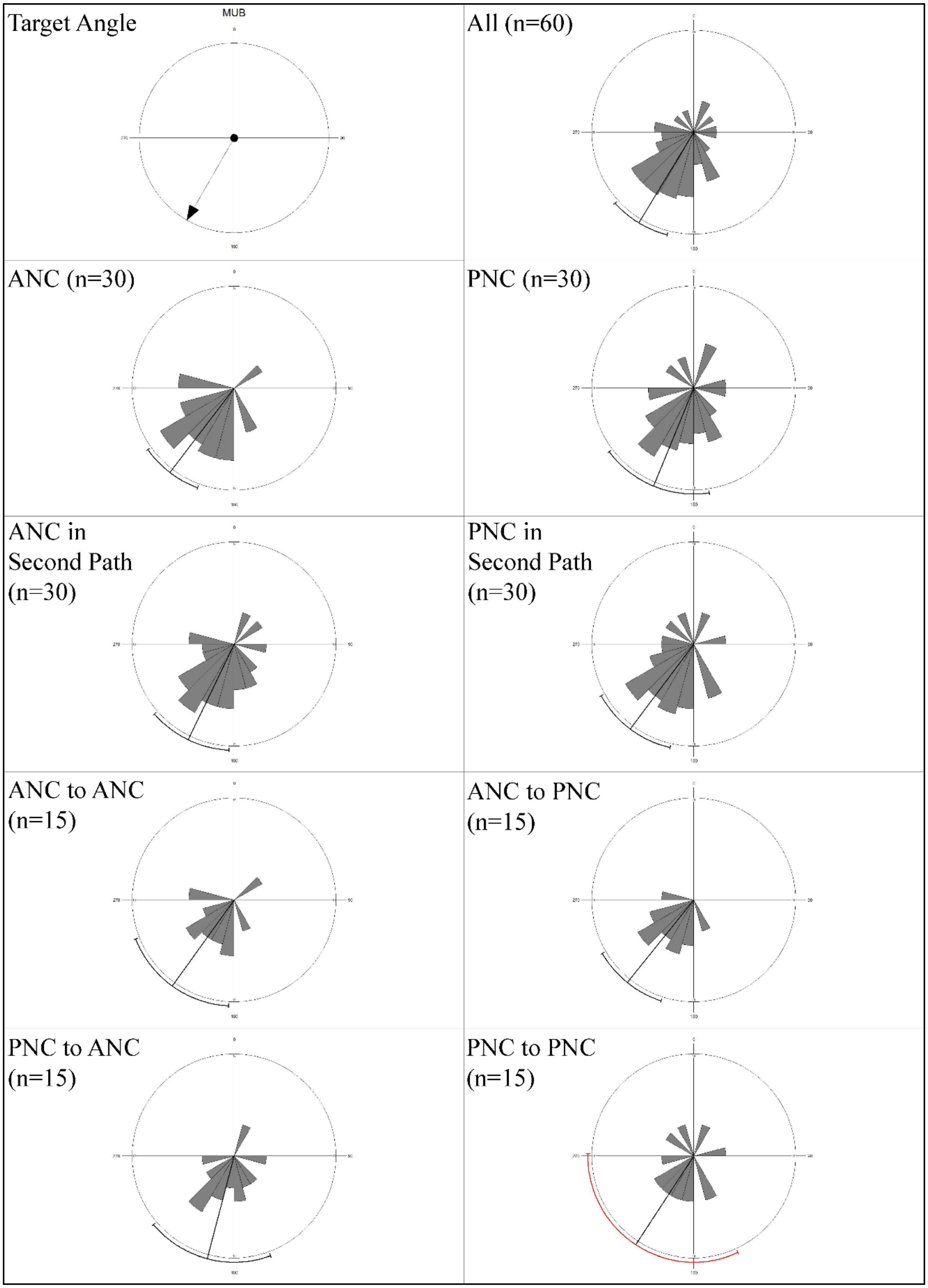
10. Kirk Hall 2



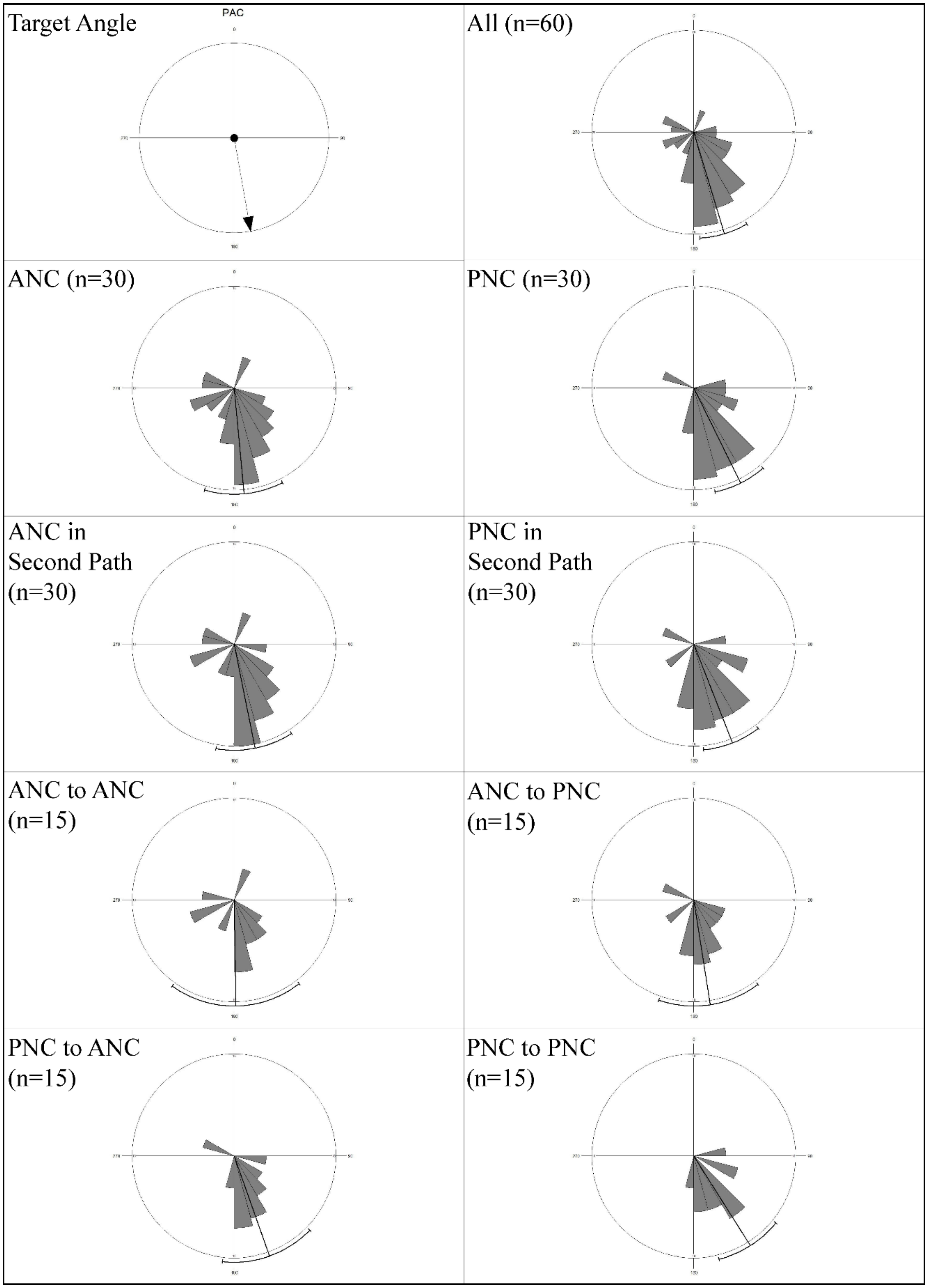
11. Marquis Hall



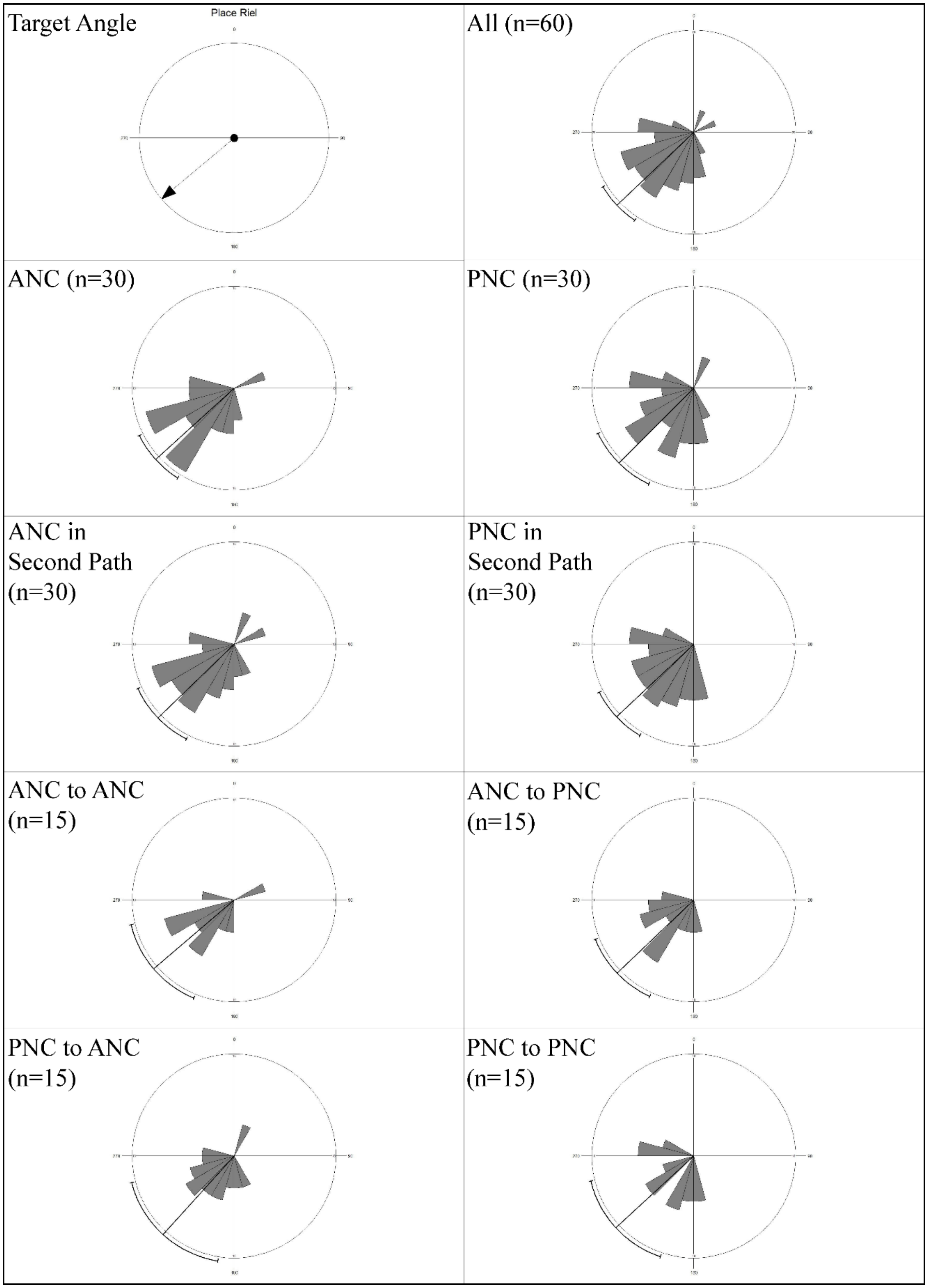
12. Memorial Union Building (MUB)



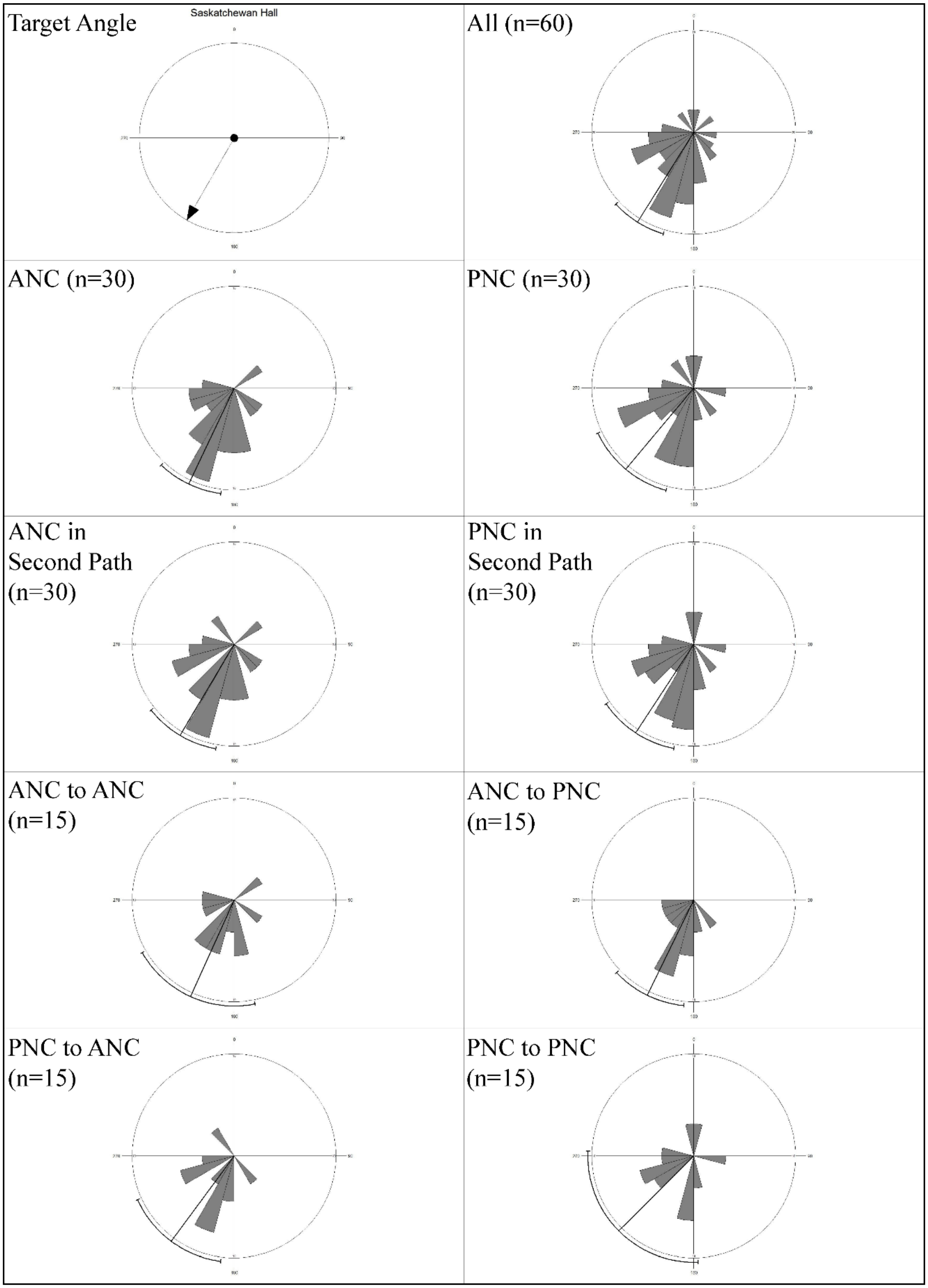
13. Physical Activity Complex (PAC)



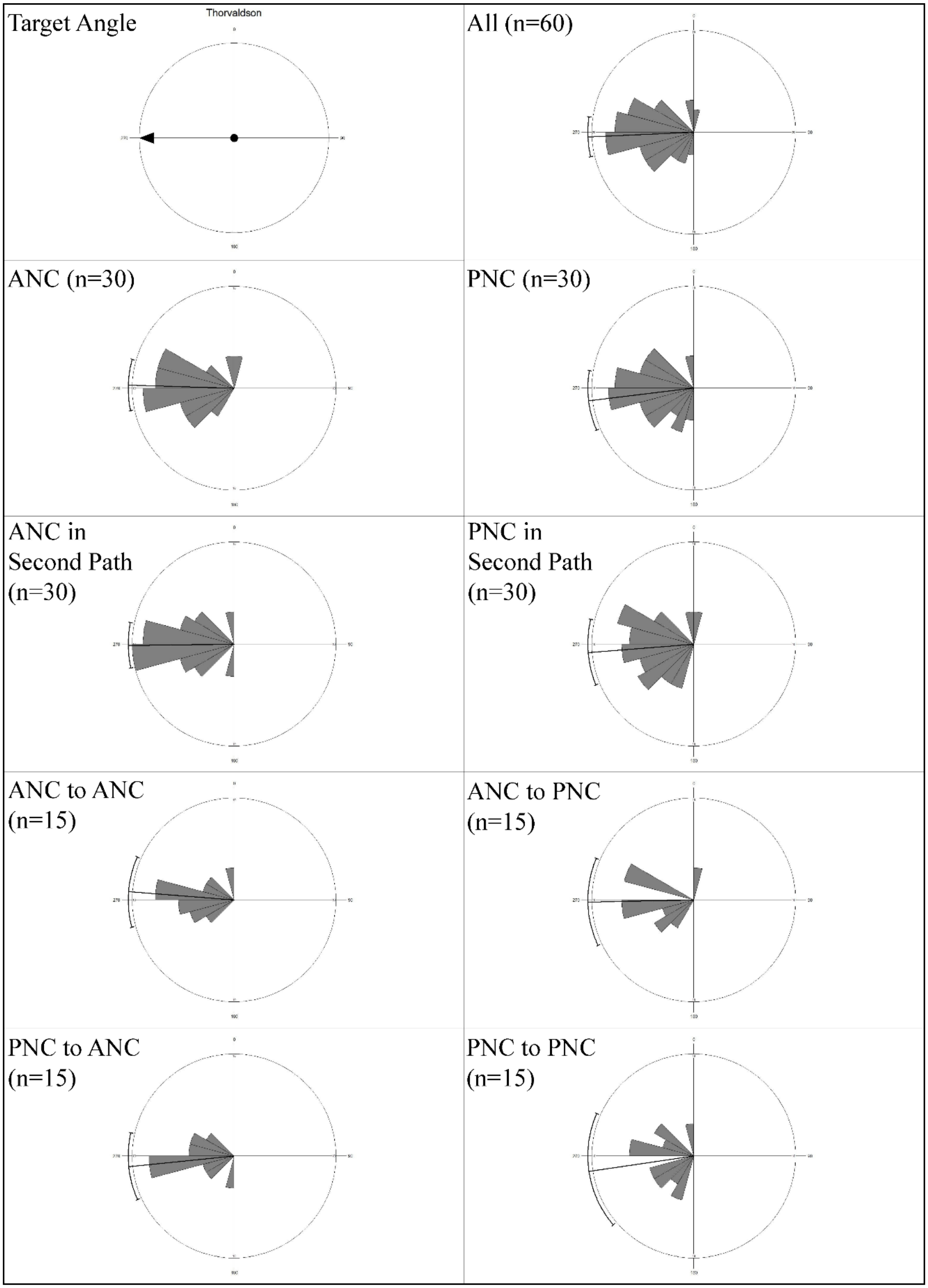
14. Place Riel



15. Saskatchewan Hall



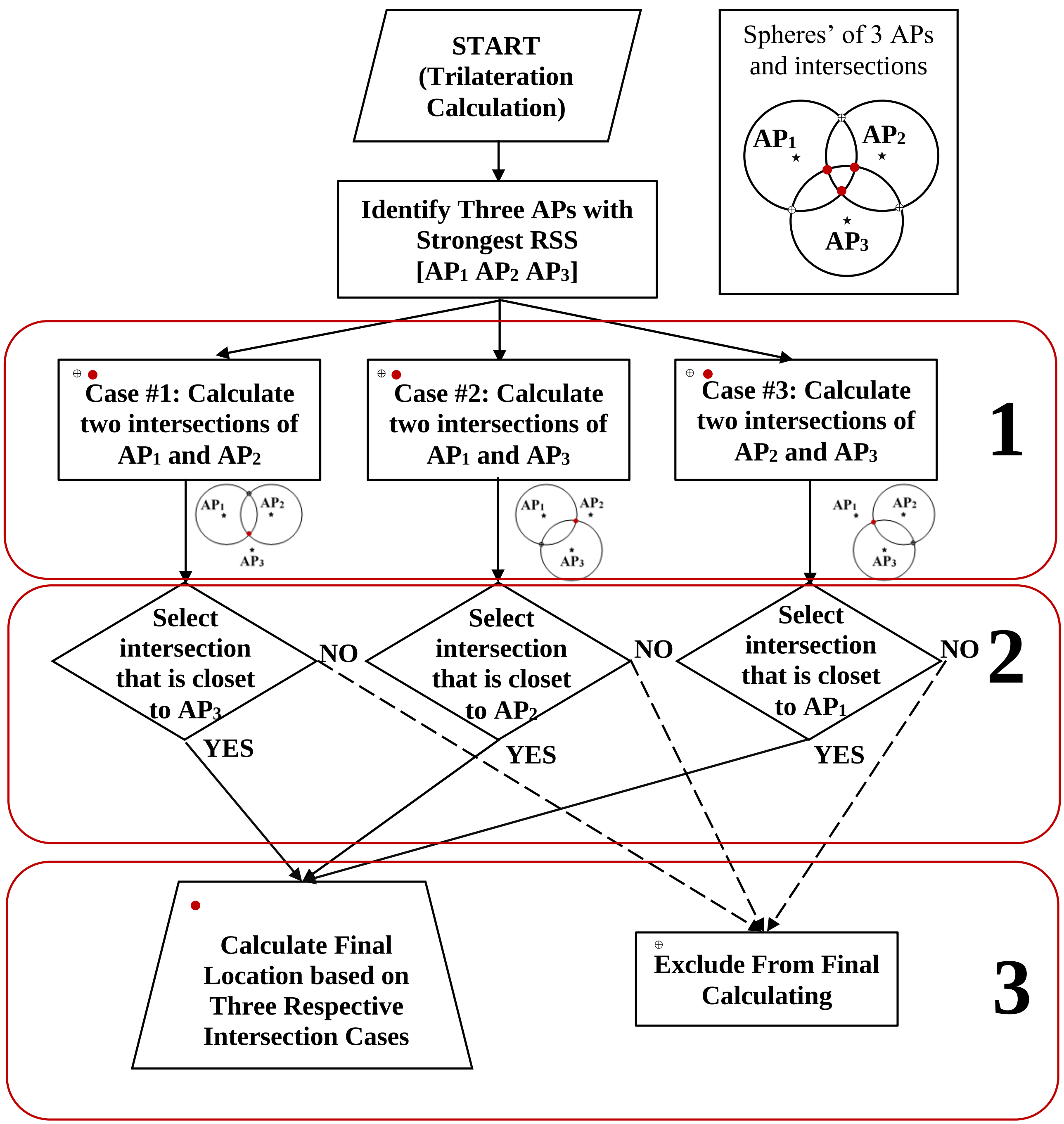
16. Thorvaldson Building



APPENDIX E

Overview of Trilateration Algorithm of SaskEPS

An example of the trilateration algorithm calculation procedures (Figure 2.4; Page 29)



1. Calculating Two Intersecting Locations

    a) Case #1: two intersections of AP_1 and AP_2

    b) Calculate sphere radius in metric distance based on Received Signal Strength (RSS)

$$r = 10^{\frac{|s| - |m| - 26.0205}{20}}$$

r: *Sphere radius (in meters) of selected AP,* ***s***: *AP's RSS in dBm,* ***m***: *Referenced RSS in dBm*

        i. Potential source of error

- ➢ Multipath and attenuated signal could cause uneven reading on RSS

    - Maximum RSS used to reduce signal strength variation

    - Non Line-of-Sight APs are filtered out through excluding unevenly scanned AP-signal which scanned less than 6 times during full beacon scanning period (10 scans)

    c) Identify Two Intersections of Two Spheres

$$r_1^2 = (x_1 - x_{c1})^2 + (y_1 - y_{c1})^2$$
$$r_2^2 = (x_2 - x_{c2})^2 + (y_2 - y_{c2})^2$$

$\boldsymbol{r_1}$ **:** *Sphere radius (meter) of* AP_1*,* $\boldsymbol{r_2}$ **:** *Sphere radius of* AP_2 *(See RSS to sphere radius)* $\boldsymbol{x_1, y_1}$: AP_1 *location,* $\boldsymbol{x_2, y_2}$: AP_2 *location*

<u>Two Identified Intersections: [x_{c1}, y_{c1}] and [x_{c2}, y_{c2}]</u>

    d) Repeat steps b) and c) for Case #2 and Case# 3

        i. Case #2: two intersections of AP_1 and AP_3

        ii. Case #3: two intersections of AP_2 and AP_3

2. Identify Three Intersections of Three Spheres

   a) Case #1: Find the closest intersection point of AP_1 and AP_2 to AP_3 location

   b) Define the closet Intersection

$$If\ (x_3 - x_{c1})^2 + (y_3 - y_{c1})^2 > (x_3 - x_{c2})^2 + (y_3 - y_{c2})^2$$

x_3, y_3: *AP_3 location*, x_{c1}, y_{c1}: *Intersection #1*, x_{c2}, y_{c2}: *Intersection #2*

Then, Intersection of Case #1 [x_{c1}, y_{c1}] is selected for final calculation

   c) Repeat steps b) and c) for Case #2 and Case# 3

      i. Case #2: Find the closest intersection point of AP_1 and $AP_3$to AP_2 location

      ii. Case #3: Find the closest intersection point of AP_2 and AP_3 to AP_1 location

3. Final Calculation

   a) Identify the centre of three spheres' intersection area

      i. Calculated Intersection #1: the closest intersection point of AP_1 and AP_2 to AP_3 location

      ii. Calculated Intersection #2: the closest intersection point of AP_1 and $AP_3$to AP_2 location

      iii. Calculated Intersection #3: the closest intersection point of AP_2 and AP_3 to AP_1 location

   b) Calculate final location

$$x_{final} = \frac{x_{f1} + x_{f2} + x_{f3}}{3}$$

$$y_{final} = \frac{y_{f1} + y_{f2} + y_{f3}}{3}$$

x_{f1}, y_{f1}: *Calculated Intersection #1*, x_{f2}, y_{f3}: *Calculated Intersection #2*,
x_{f3}, y_{f3}: *Calculated Intersection #1*

Then, final location [x_{final}, y_{final}]

APPENDIX F

Enhanced Positioning Systems: Accuracy through Mapping, Calibration, and Classification[3]

ABSTRACT

Enhanced-positioning systems are able to support the acquisition of accurate location information using wireless technology other than the Global Positioning System (GPS). These systems have the potential to supplement GPS where GPS is unreliable. In particular, enhanced-positioning systems can provide location information for navigational support and Location Based Services (LBS) indoors and in dense urban canyons and natural environments with extreme relief. The emergence of LBS and the widespread adoption of GPS-based navigation systems are largely a result of the accuracy with which GPS devices can determine location. The purpose of this study is to validate Wireless internet access points (WiFi APs) for determining location. A WiFi-based position system, tentatively called SaskEPS (Saskatchewan Enhanced Positioning System) has been developed, calibrated, and implemented for two multi-floor buildings on the University of Saskatchewan campus. Locations are calculated using four discrete steps (or sub-routines) Step 1. Accurate database of AP locations, 2. Calibration of signal strength and conversion to distance 3. Determination of line-of-sight from non-line-of-sight APs and assignment of correction factor to non-line-of-sight, and 4. Trilateration based on three or more router locations and derived distances. The results of an experiment testing the accuracy and reliability of locations calculated with the system show GPS-like accuracy with relatively low continuous (distance) and nominal (placement on correct floor of a multi-floor building) uncertainty.

Keywords

WLAN coverage, WiFi mapping, WiFi-based positioning system, trilateration, Location Based Services (LBS)

1. INTRODUCTION

Just as the removal of selective availability by Presidential decision directive in 1996 caused dramatic growth in the use of personal GPS devices, the emergence of GPS-enabled smartphones has made Location Based Services popular (Clinton 2000). LBS and the widespread adoption of GPS-based navigation systems have their genesis in the accuracy and reliability of GPS devices. Navigation and wayfinding

are a routine part of our daily life and supplementing it with technology requires high positional accuracy and dynamic updating. Navigation technology based on GPS positioning has become increasingly ubiquitous as we strive for efficient and successful wayfinding. Navigation can be described as purposeful locomotion to reach a destination through space [8].

LBS is associated with delivering information regarding commercial, public, and other services in the area surrounding the user of a mobile device, navigation might be considered a special case of LBS [9]. Cell phone operating systems including Android, iPhone, and Windows Mobile are making it easier for software developers to integrate a person's current location into information

[3] The full citation of the published chapter is: Bell, S., W. Jung, W. R., and Krishnakumar, V. (2010). Enhanced Positioning Systems: Accuracy through Mapping, Calibration, and Classification. Proceedings of the Second ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness. San Jose, California, ACM: 3-9. doi: 10.1145/1865885.1865888. This article is re-printed according to ACM Author Rights and Publishing Policy.

retrieval and delivery. However such services cannot be extended to indoor environments because of the relatively weak radio signal of GPS; however, the development of new location systems that can function with GPS-like accuracy in areas that GPS does not work is an active and important area of research [2].

Many mobile devices, such as cell phones, smartphones, and laptops already provide LBS relying on GPS-based location as well as the more uncertain location derived from WiFi or cellular systems. Uncertainty and the consumers' lack of awareness of it are problems that must be addressed before widespread deployment of non-GPS location systems can be realized, particularly for point-to-point navigation and widespread LBS. It seems apparent that the viability of any non-GPS system (including GPS's soon to be available European counterpart, Galileo) depends on achieving the location accuracy of GPS (sub-10 metre accuracy). The integration of GPS and non-GPS location systems, also called Enhanced Positioning Systems, takes advantage of available location information from GPS to inform non-GPS systems when moving from outdoor to indoor settings.

The technologies that could theoretically provide EPS have strengths and weaknesses. GPS does not work indoors or in areas with limited line-of-sight to the sky (urban and natural canyons), it is this limitation that makes the development of EPS so enticing. In general, positioning systems' limitations fall into five categories: 1. non-global coverage, 2. accuracy, 3. security, 4. signal confusion, and 5. power consumption. Considering each location system in turn (GPS included) their weaknesses include:

- **GPS** (signal confusion and power consumption): GPS is advantageous in terms of positioning accuracy and reliability in outdoor settings but is unreliable indoors and in dense urban and natural canyons because of signal multipath, scattering, and attenuation [16]. These delays in signal acquisition may consume more power than systems relying on local signals. [14].

- **Assisted GPS** (signal confusion): Assisted GPS (A-GPS) integrates GPS functionality with cell phone technology [14]. A-GPS takes measurements of signals from nearby cell phone towers and reports time and distance readings back to the network to increase the response rate of the GPS [15].

- **GSM** (accuracy and security): the Global System for Mobile communication (GSM) is a digital cell phone protocol used around the world. However, since the technology was developed to support telecommunication the nominal array of towers through which a device communicates is sparse. The optimal array (from an economic perspective) would be the minimum number of towers to cover the expected number of users and call volume. The relatively long range of communication, compared with WiFi and Bluetooth, results in location uncertainty when compared to all other positioning systems.

- **Bluetooth Technology** (non-global coverage): Bluetooth wireless technology was developed as a global standard for short-range data transfer between devices [1]. Bluetooth is essentially a short-range cable-replacement protocol [7]. Bluetooth technology in most mobile devices has a range of less than 10 meters. A Bluetooth system would require an AP array much denser than WiFi.

- **WiFi Technology** (accuracy, signal confusion, and security): IEEE 802.11 b/g/a/n represent standard WiFi protocols defined by raw data transfer rate and signal frequency. For indoor LBS, WiFi is a common technology for localization [13]. WiFi-based services also have potential security risks including location spoofing and location database manipulation attacks [11]. Furthermore, ubiquitous coverage is necessary for such a system to be viable, a characteristic that might only be present in limited environments.

2. SASKATCHEWAN ENHANCED POSITIONING SYSTEM (SaskEPS)

The study of WiFi availability, its pervasive presence in the urban landscape, and the development WiFi-based EPS is widespread. Geographers have documented the “cloud” of WiFi signals that cover and overlap in urban areas [12]. WiFi has become an increasingly ubiquitous resource in different settings (urban and shared, institutional and private, etc.) and its availability has resulted in a variety of applications for which it was not initially intended.

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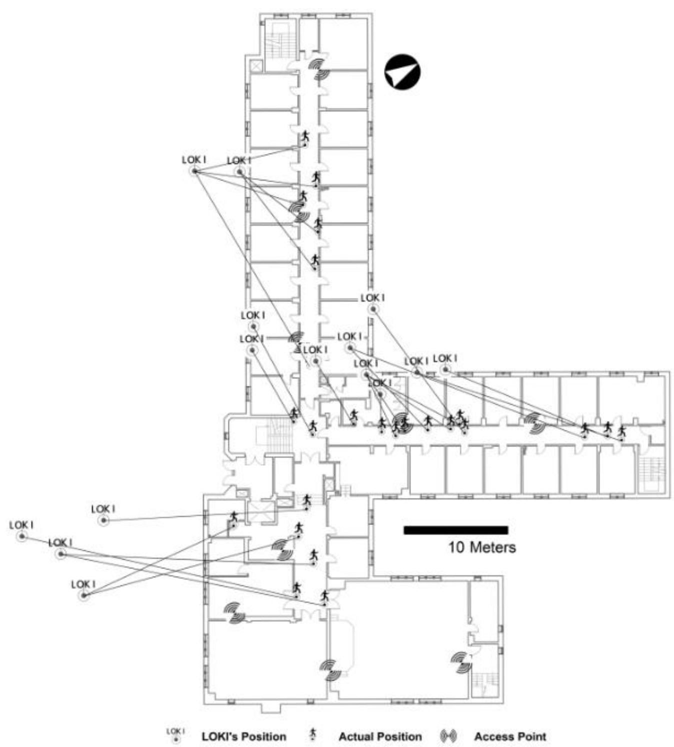

Figure 1. “LOKI” dots represent locations determined with LOKI while human form represent correct locations derived from ArcGIS.

EPS has the potential to provide accurate location information by taking advantage of wireless technology and in turn being integrated with existing global positioning systems (GPS) [5]. Many existing LBS use WiFi technology as an alternative indoor positioning source; unfortunately most fail to provide sufficient accuracy or clearly communicate levels of location uncertainty [3]. For example, Skyhook, provides a widely used hybrid positioning system that combines GPS, GSM, and WiFi for use on laptops, smartphones, and other mobile devices [10]. It is important to note that a critical element in a successful WiFi-based positioning system is accurate access point (AP) IDs and locations for use in determining a devices' current location [4]. Skyhook, LOKI, and others have been collecting AP location information and measuring signal strength through web-based updates, purposeful signal detection to determine AP location ("wardriving"), and passive signal detection and communication with individual vendors (Skyhook, LOKI, etc.). In a recently test we found locations with Skyhook and LOKI could be hundreds of metres from the correct locations; we found two locations in our test environment with greater than 500 metres of error and one location that was over 10 km from the correct location. These errors are likely the result of a mistake when AP locations were entered on Skyhook's website (either a wrong address/coordinate pair or a misplaced "pin" on the interactive map). Even with such outliers removed the average difference between the correct locations and Skyhook locations was over 100 metres (figure 1 shows visually the error associated with locations determined using LOKI; figure 2 show error associate with location determined using iPhone 3Gs; tabular and graphical results are presented in the Results section below).

ENGINEERING BUILDING

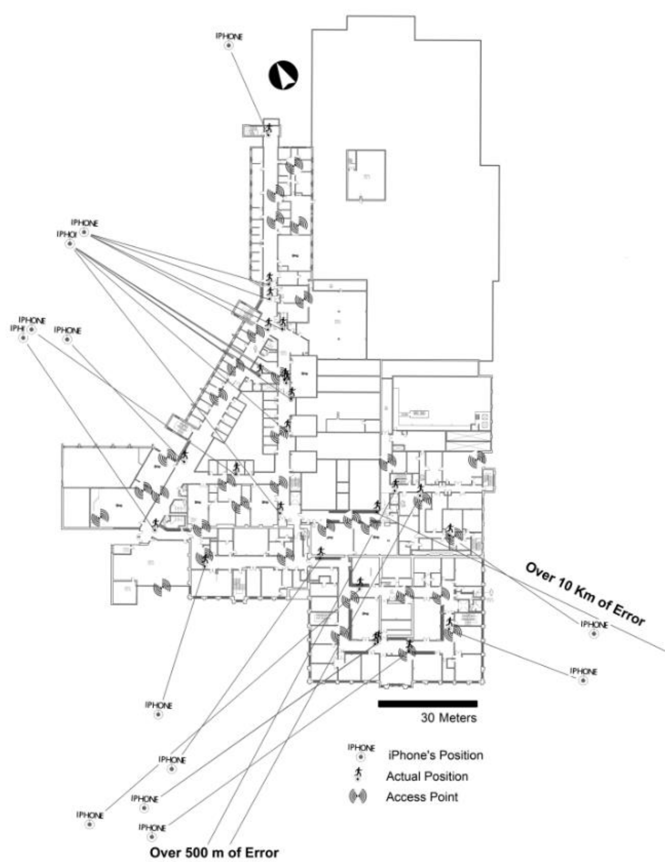

Figure 2. "IPhone" dots represent locations determined with LOKI while human form represent correct locations derived from ArcGIS.

More accurate WiFi location systems rely on one of two location methods. Many current systems rely on fingerprinting which involves the matching of a device's observed APs and signal strengths with a database of locations that would “see” that same arrangement of APs (essentially comparing the fingerprint from a location in space with fingerprints in a database) [3, 6]. An alternative to fingerprinting is to use a trilateration algorithm similar to GPS. A similarity shared by the two methods is the need for an accurate database of AP locations and the ability to detect signal strength with consistent sensitivity. Any error or uncertainly in the databases record of AP locations will be manifested (and magnified) in derived locations.

For both systems the reliance on an accurate and up-to-date database results in one of their most glaring challenges. In both systems updates or changes to the WiFi network throughout the environment in which the system functions must be present in the database or errors in positioning will occur. This is a much greater problem for fingerprinting as the installation or removal of a router will change all of the fingerprints for locations within range of that new or removed router. Furthermore, in order to adopt a change to the router network fingerprints for affected all spaces must be updated. A trilateration system that does not rely on fingerprinting for positioning will also produce location errors as it is not taking advantage of the most detailed network of locations for trilateration. In such a system if a router is “visible” but not in the database it will simply be skipped over during the trilateration step. We have not tested the change in accuracy of our system during the removal of a small subset of routers, but this would be a relatively simple experiment to conduct in the future.

2.1 Adding Value to a WiFi Network

The University of Saskatchewan (U of S) provides a dense publicly available WiFi network across both indoor and outdoor spaces. The core campus is covered by a dense array of APs offering more than two visible routers from most locations. The campus does provide router location information to Skyhook; unfortunately, this information appears to be limited to street address information or clicking on a low resolution web map, each of which results in additional uncertainty. All campus routers have been installed and are maintained by Information Technology Services (ITS); this same unit has historically been responsible for updating AP information on the Skyhook website. While the installation of a 3rd party wireless router is possible, the explicit policy of ITS is that such routers are not allowed. In fact, ITS is generally responsive to requests for additional access points if unserviced or weakly serviced spaces are identified. For our purposes we focused on the most public spaces on campus through which navigation is most likely to occur. This includes hallways, tunnels, skywalks, building foyers, and other public open spaces. It *did not* include classrooms; these rooms represent somewhat special spaces on campus. Generally a classroom is a destination, just like a departmental, administrative, or faculty office, so the capacity to accurately calculated location within such spaces seems less important. On the other hand, for many classrooms there are often multiple routers due to high demand and relatively low bandwidth over WiFi (as of 2010 the campus capped WiFi bandwidth through routers to 11 mbps). Therefore, we decided that if within classroom locations became important (perhaps for disability access) it would be a relatively easy problem to tackle with a high likelihood of greater accuracy and less variance than is found for non-classroom spaces in the current application.

The current system uses a trilateration algorithm based on distances from three or more unique AP locations. Distances are estimated based on recorded signal strength from “visible” APs (those routers from which a signal can be detected by the wireless adaptor on a mobile device, in this case one of two laptops). In addition to trilateration, two additional steps are used to decrease uncertainty: 1. calibration of AP signal strength, and 2. a nominal assessment of whether an AP is in a line-of-sight location from the laptop (no signal interference by floors, walls or other structures). In addition to the accurate database of AP IDs and their locations, these three steps help the SaskEPS produce locations with coordinates within 10 metres of their actual locations (actual locations determined during random point selection in ArcGIS).

2.2 Database Creation

There are more than 700 wireless APs currently installed (through summer, 2010) on the U of S campus. All campus APs were installed by the U of Saskatchewan Information Technology Services (ITS) in a consistent manner and those APs' spatial information is maintained by university's Facilities Management Division (FMD). Both base map and CAD-drawn blueprints were used in our AP mapping process; blueprints were georeferenced to NAD 83 UTM Zone 13 North coordinate system with ArcGIS™ 9.3.1. Georeferenced images were used to locate and digitize APs on the campus map. After comparing these with spreadsheet information from ITS, discrepancies were apparent and noted. Field inspection of all APs was performed to ensure that digitized APs were placed in the correct location; finally, AP Media Access Control (MAC) addresses were also validated for all APs. The final product is a database of AP MAC addresses (representing a unique ID) with accurate locations recorded in UTM Zone 13 N coordinates. This database is the backbone of the system and allows for accurate trilateration of any location within the range of 3 or more router locations; it is important to note that not all routers within range need to be line-of-sight.

2.3 System Requirements and Structure

SaskEPS current runs on computers with Microsoft Windows Vista or Windows 7 operating systems installed. Currently the system has been tested on two sets of laptops: one group running either B, G, or N WiFi protocol wireless adaptors (latest technology) and one group running B, G, or A WiFi protocol adaptors (older WiFi technology with lower bandwidth capacity and presumably weaker antennae). The software code is written in C#; we anticipate translation to Windows Mobile operating system in the future.

The first step is the calibration of signal strength and conversion to distance; this procedure does not need to be repeated for the same network of APs. Placing the computer running the application exactly 20 feet from a single router the calibration subroutine provides the application with a baseline for estimating distance from signal strength for line-of-sight routers (figure 3), this baseline is also used for non-line-of-sight routers, but an additional step is required.

The second step involves running the main application algorithm. The algorithm scans the surrounding environment for wireless signals. The full scan involves 10 individual scans for "visible" and unique APs (the AP's MAC address) and signal strength; each scan lasts 2 seconds. Two pieces of information are extracted from the scan: 1. average signal strength (which is then converted to distance) and 2. the number of times out of 10 scans that each router's signal was detected and recorded. The latter step provides reliable information regarding whether a router is in a line-of-sight position from the device running the program. This allows for a position to be placed on the correct floor of multi-floor buildings as well as on the correct hallway segment for buildings with multiple halls on each floor (figure 2). The final step is trilateration. However, before distances are used to trilaterate location a correction factor is added to all average signal strengths recorded from non-line-of-sight routers (return <10/10 scans) to adjust for degradation in signal strength from such routers. This is a relatively crude method, but in fact increases the overall accuracy of the system. As will be discussed later this is also an exciting area for future development through the production and refinement of a more probabilistic correction factor based on the actual number of successful scans out of 10. Once APs are assigned to either the line-of-sight or non-line-of-sight categories a single correction factor for all non-line-of-sight routers is applied to the signal strength. The final step in the application is the trilateration of position based on distance derived from signal strength (figure 4).

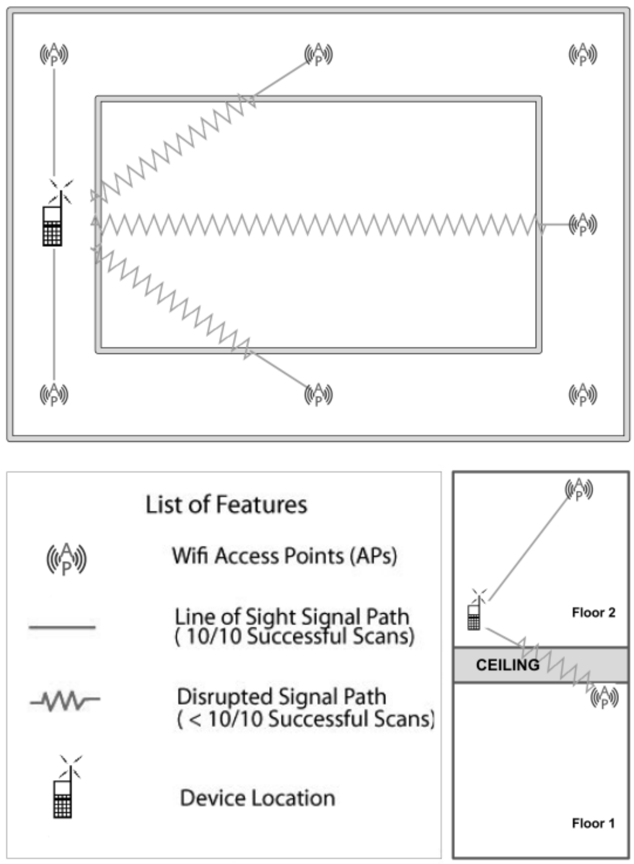

Figure 3. WiFi signals can be degraded by structural walls on the same floor as the device or by floors/ceiling between floors.

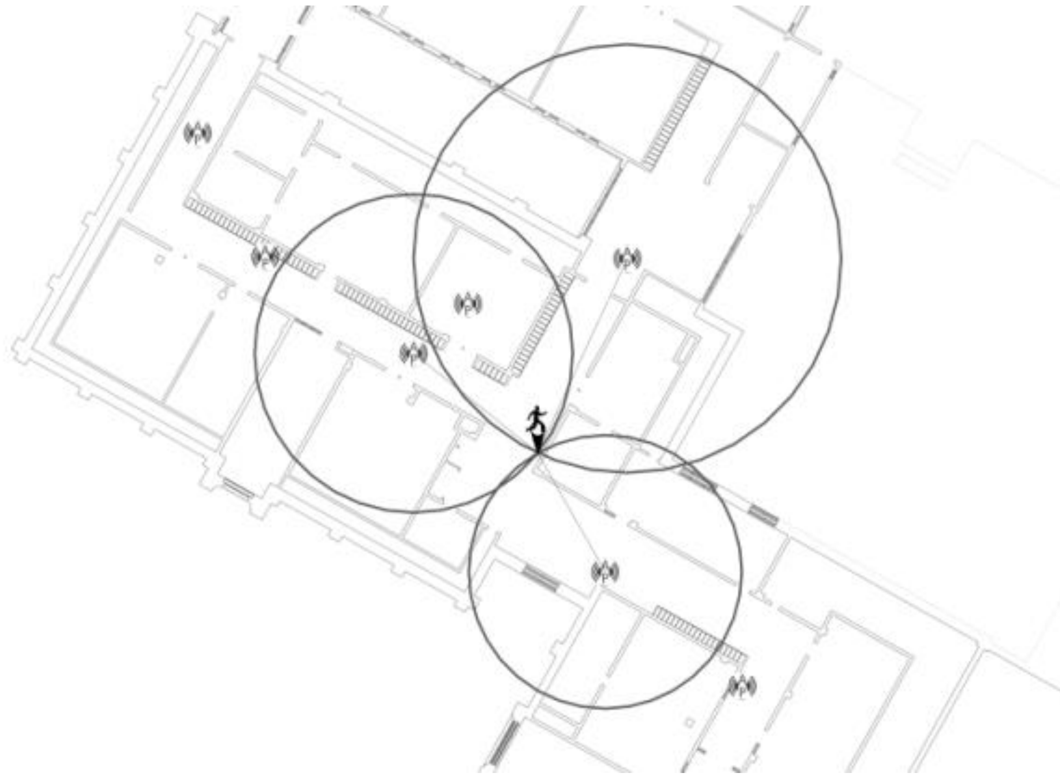

Figure 4. Conceptual diagram of trilateration from three visible APs.

3. METHODS

A psuedo-experiment was conducted in two multi-floor buildings at the University of Saskatchewan; the two buildings are Kirk Hall (home of Geography and Planning) and the Engineering Building. Each building has unique characteristics that make testing generalizable to a variety of indoor settings. Each building contains three floors; Kirk Hall has two hallways that intersect at right angles (figure 1 and 4), Engineering has 5 hallways that intersect at several angles (figure 2 and 5). Furthermore, Kirk Hall has wireless APs at regular intervals in a "stacked" arrangement; all floors have the same arrangement of routers (individual routers are in the same location on each floor). Engineering has a more irregular floor-by-floor arrangement, although each floor has the same total number of APs.

KIRK HALL

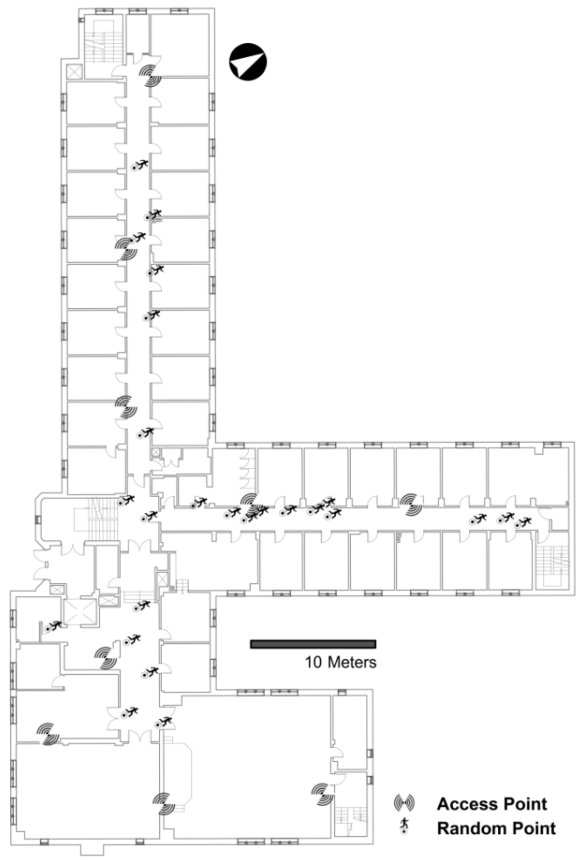

Figure 4. Kirk Hall (first floor) with WiFi AP locations and experimental locations.

25 random points were selected for each floor in each building. Randomization was performed by creating a regular lattice of points at 1m intervals for each hallway polygon for each floor and randomizing all points for each floor and sequentially selecting the first 25 points for each floor. UTM coordinates were extracted for each point using ArcGIS. These UTM coordinates provide the correct location for each experimental point (see figures 4 and 5). Following calibration each point was visited and its location determined using the EPS application. Points were visited in the morning and evening to allow for comparison of high and low traffic/use times. In addition, two publicly available WiFi-based location systems were tested at each experimental point. Skyhook running on a 3Gs iPhone and Loki running on a laptop were used to calculate location coordinates.

ENGINEERING BUILDING

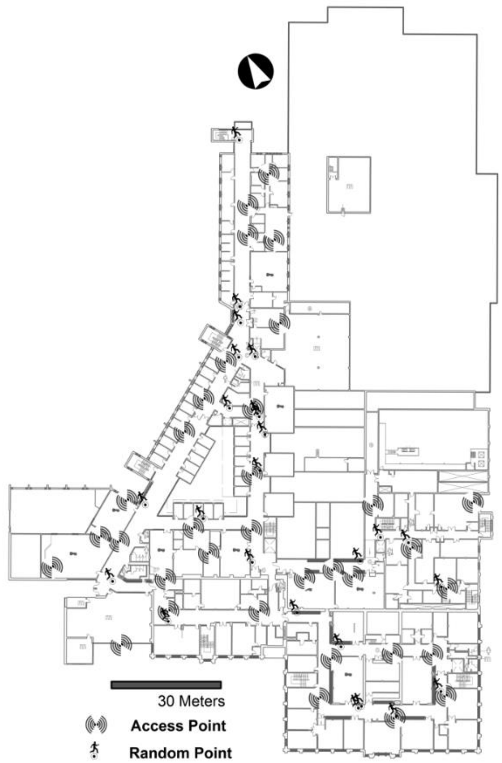

Figure 5. Engineering building (first floor) with WiFi AP locations and experimental locations.

4. RESULTS

For both buildings on all floors the EPS returned locations reliably with less than 10 metres of error (table 1). The regular arrangement of APs in Kirk Hall produced slight lower error, but with shorter hallways this building also had lower maximum distance from a visible AP. Locations calculated in the evening were somewhat more accurate than morning locations. This difference is likely attributable to reduced WiFi traffic and therefore a cleaner signal. In all settings the average error was less than 10 metres (in both buildings average error approached 5 metres) with the standard deviation of location error less than 5 metres for Kirk Hall and slight greater than 5 metres in the Engineering building. Location accuracy in both buildings far exceeded that of results for Skyhook and Loki technology. Interestingly, Loki and Skyhook results are different from one another even though Loki relies on data from Skyhook for location determination.

All locations were assigned to the correct floor (based on floor of closest line-of-sight AP) and no locations were placed outside of a building`s structure. This latter finding was interesting as our system did not evaluate the presence or absence of a GPS signal at a test location. An additional subroutine to check for a GPS signal will be included in the future to increase accuracy (any location that is not inside a building should have access to the GPS signal, therefore all locations relying solely on WiFi for position should be located inside buildings).

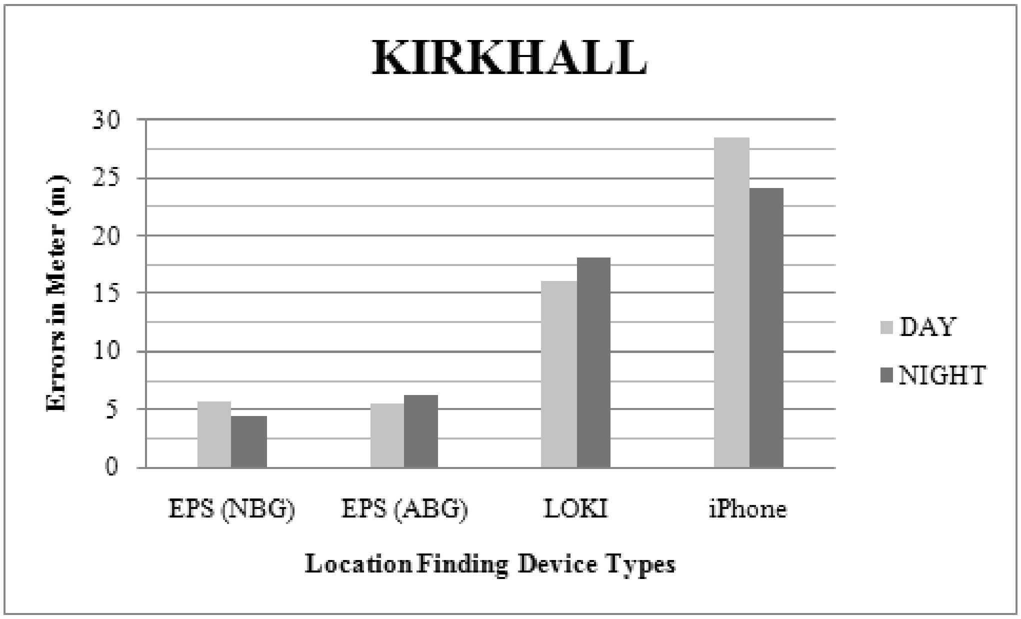

Figure 5. Kirk Hall location error from SaskEPS, LOKI, and iPhone. EPS/NBG is the SaskEPS running on a laptop with latest WiFi adaptor, EPS/ABG is SaskEPS running on an older WiFi adaptor.

KIRK HALL				
	EPS/NBG	**EPS/ABG**	**LOKI**	**IPHONE**
AVE. Error Day	5.71 m	5.43 m	16.14 m	28.57 m
SD. Day	4.13 m	4.68 m	9.03 m	14.39 m
AVE. Error Night	4.42 m	6.19 m	18.04 m	24.06 m
SD. Night	3.24 m	5.75 m	7.88 m	11.28 m

Table 1. Kirk Hall location error.

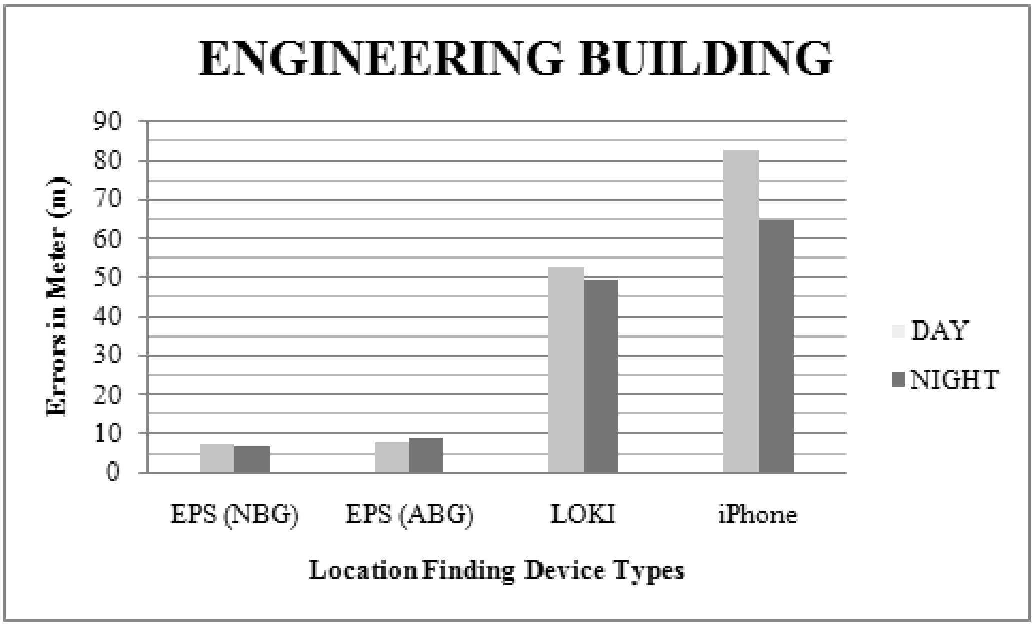

Figure 6. Engineering building location error.

ENGINEERING BUILDING				
	EPS/NBG	**EPS/ABG**	**LOKI**	**IPHONE**
AVE. Error Day	7.46 m	7.64 m	52.83 m	82.92 m
SD. Day	6.70 m	6.25 m	36.66 m	64.60 m
AVE. Error Night	6.49 m	8.88 m	49.48 m	64.62 m
SD. Night	5.41 m	6.26 m	34.29 m	20.50 m

Table 2. Engineering building location error.

As indicated above, locations calculated by publicly available systems had substantially higher errors. Errors for iPhone locations were consistently greater than 20 meters and on several floors were greater than 50 meters; Loki locations were more accurate but had greater variance. For both public systems variance was substantially higher than the SaskEPS locations.

5. CONCLUSIONS

EPS can provide seamless positioning service in indoor and outdoor environments in which GPS is unreliable. Pseudo-experimental results for the SaskEPS indicate that such a system can be used to generate locations with GPS-like accuracy. The evolution of mobile devices places high demand on new functionality; the proposed system can be used as an additional feature on WiFi enabled smartphones and other WiFi enabled devises. Such an advance is the necessary first step towards developing LBS for indoor spaces that are incompatible with simply finding the front door or the correct entrance to a building. Such problems include finding the correct departure gate in a large airport, finding an office in a multifloor, large footprint office building, tracking product in multi-building warehouses, etc. An important benefit of SaskEPS, and other Wifi-based positioning systems, is its reliance on existing infrastructure that is already widely deployed in similar indoor environments (WiFi APs). Furthermore, its higher accuracy and reliability will trigger EPS related services and software because of the extensive availability of WiFi. In addition, EPS can provide location aware service without requiring additional hardware; the user simply downloads the software-based application to their mobile device runs the calibration routine and is ready to locate themselves.

While deployment of SaskEPS across the university campus is expected to be successful beyond the two test buildings, there are several expected updates that will increase accuracy, improve real-time position updating, and support location determination in spaces with no line-of-sight AP (the obvious space of this type is stairwells). More accurate and subtle correction factors for occluded signals will increase trilateration accuracy. Angular information will help determine the location of the structural occlusion between the device and the signal source. Such an upgrade will support a continuous or multi-value correction. The integration of an additional signal monitoring system that more frequently (constantly) updates the signal strength from the closest line-of-sight AP will allow for location updates along a given hallway, either towards or away from that AP location. Finally, we anticipate the first solution (continuous correction factor for signals coming from occluded sources) will also help increase accuracy for spaces with no line-of-sight APs.

Systems such as SaskEPS and related WiFi-based positioning sytems (whether trilateration-based or using fingerprinting) are emerging as important value-added tools for LBS. With increasing focus on indoor spaces, adapting systems for the disabled, and further integration with transportation and navigation systems these tools will become a part of our daily lives.

6. ACKNOWLEDGMENTS

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